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Nakata et al.

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(54) **VALVE TIMING CONTROL APPARATUS**

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(22) Filed: **Apr. 8, 2014**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

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F02D 13/02	(2006.01)
F01L 31/06	(2006.01)

(52) **U.S. Cl.**

CPC ***F02D 13/02*** (2013.01); ***F01L 31/06*** (2013.01); *Y02T 10/18* (2013.01)

(58) **Field of Classification Search**

CPC F01L 1/344; F01L 1/3442; F01L 2001/34459

USPC 123/90.15–90.18

See application file for complete search history.

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Assistant Examiner — Daniel Bernstein

(74) *Attorney, Agent, or Firm* — Nixon & Vanderhye PC

(57) **ABSTRACT**

A valve timing control apparatus includes a temperature sensing member which expands at a main lock phase when a temperature of an engine is higher than or equal to a predetermined temperature so as to prohibit a main lock component from moving out of a main lock hole to a guide slot. The temperature sensing member shrinks at the main lock phase when the temperature of the engine is lower than the predetermined temperature so as to allow the main lock component to move out of the main lock hole toward the guide slot.

6 Claims, 17 Drawing Sheets

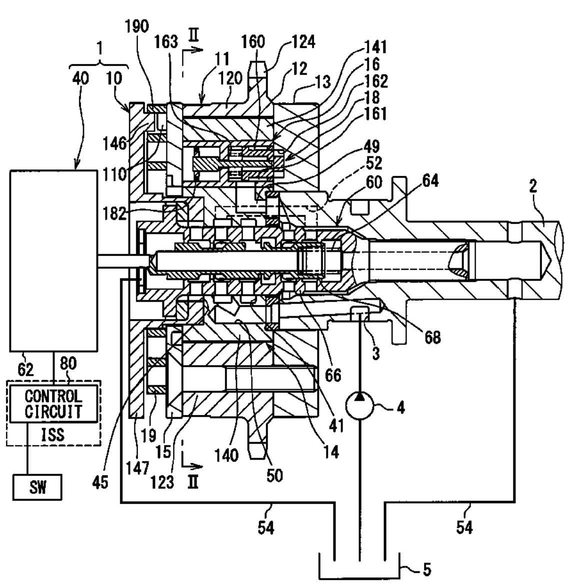
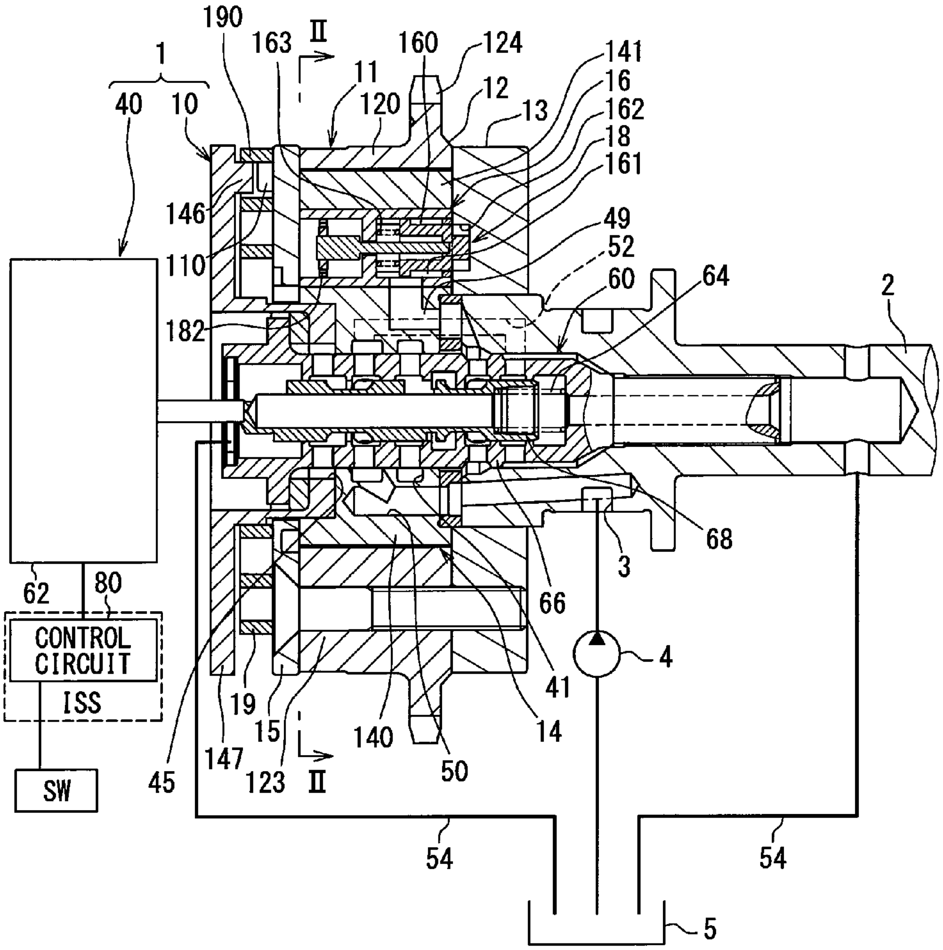


FIG. 1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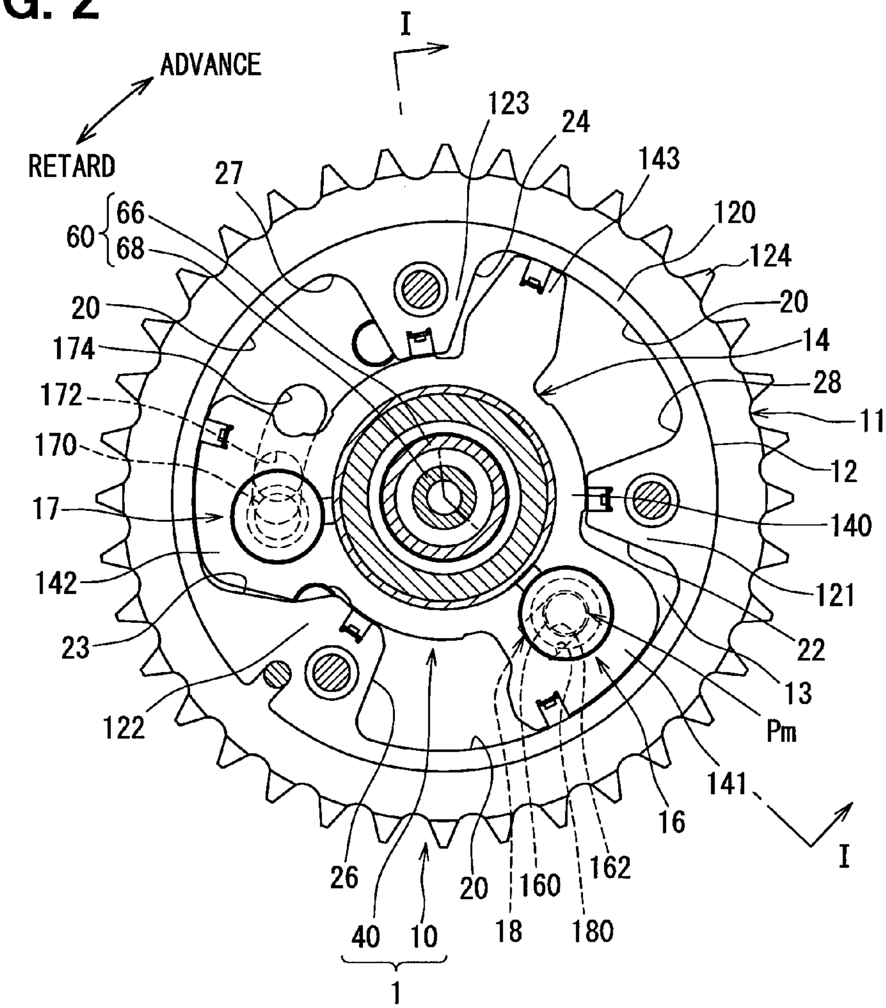
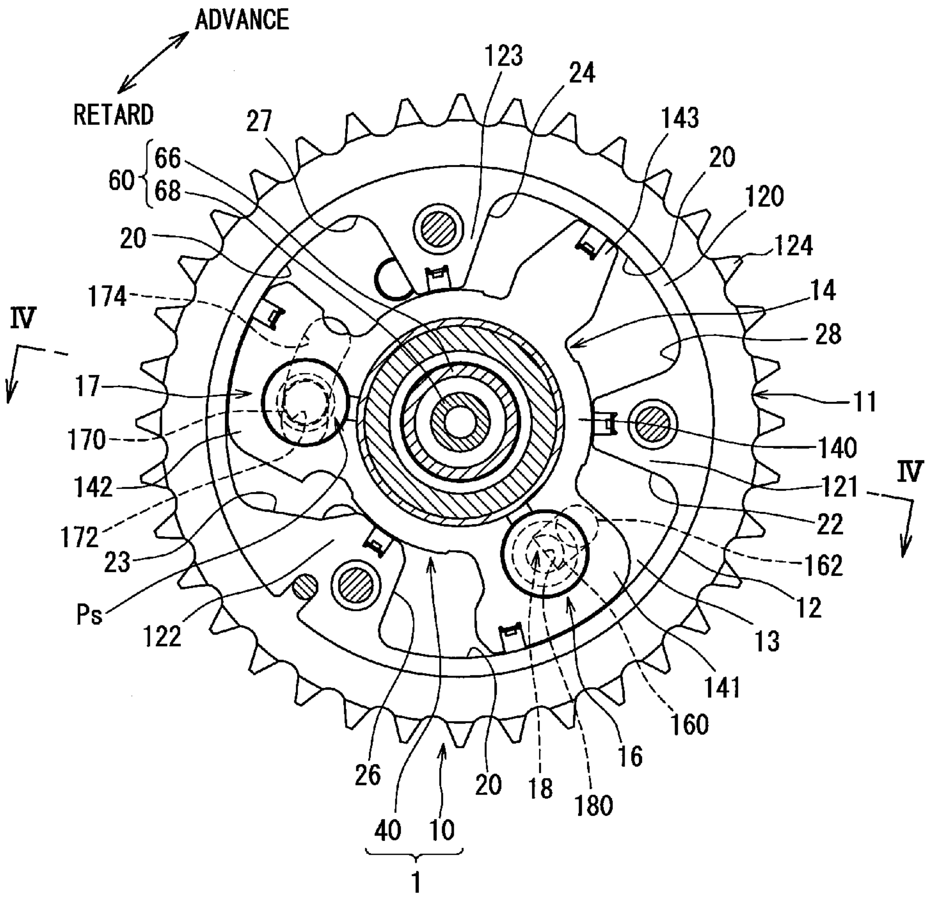
60
64
2
182
68
3
66
4
62
80
CONTROL CIRCUIT
ISS
SW
19
15
140
41
14
45
147
123
II
50
54
54
5

FIG. 2



ADVANCE
RETARD
I
I
123
24
143
120
124
20
14
28
11
12
140
121
22
13
Pm
141
16
162
180
160
18
20
10
40
1
26
122
23
142
17
170
172
174
20
68
66
60
27

FIG. 3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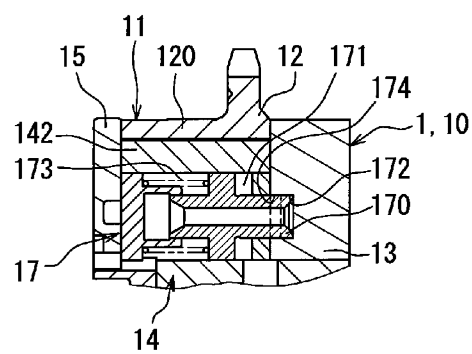
20
60
66
68
120
124
174
14
IV
28
17
11
170
140
142
121
IV
172
22
23
162
Ps
12
122
13
141
160
26
16
20
18
180
40
10
1

FIG. 4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15
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174
142
1, 10
173
172
170
17
13
14

FIG. 5

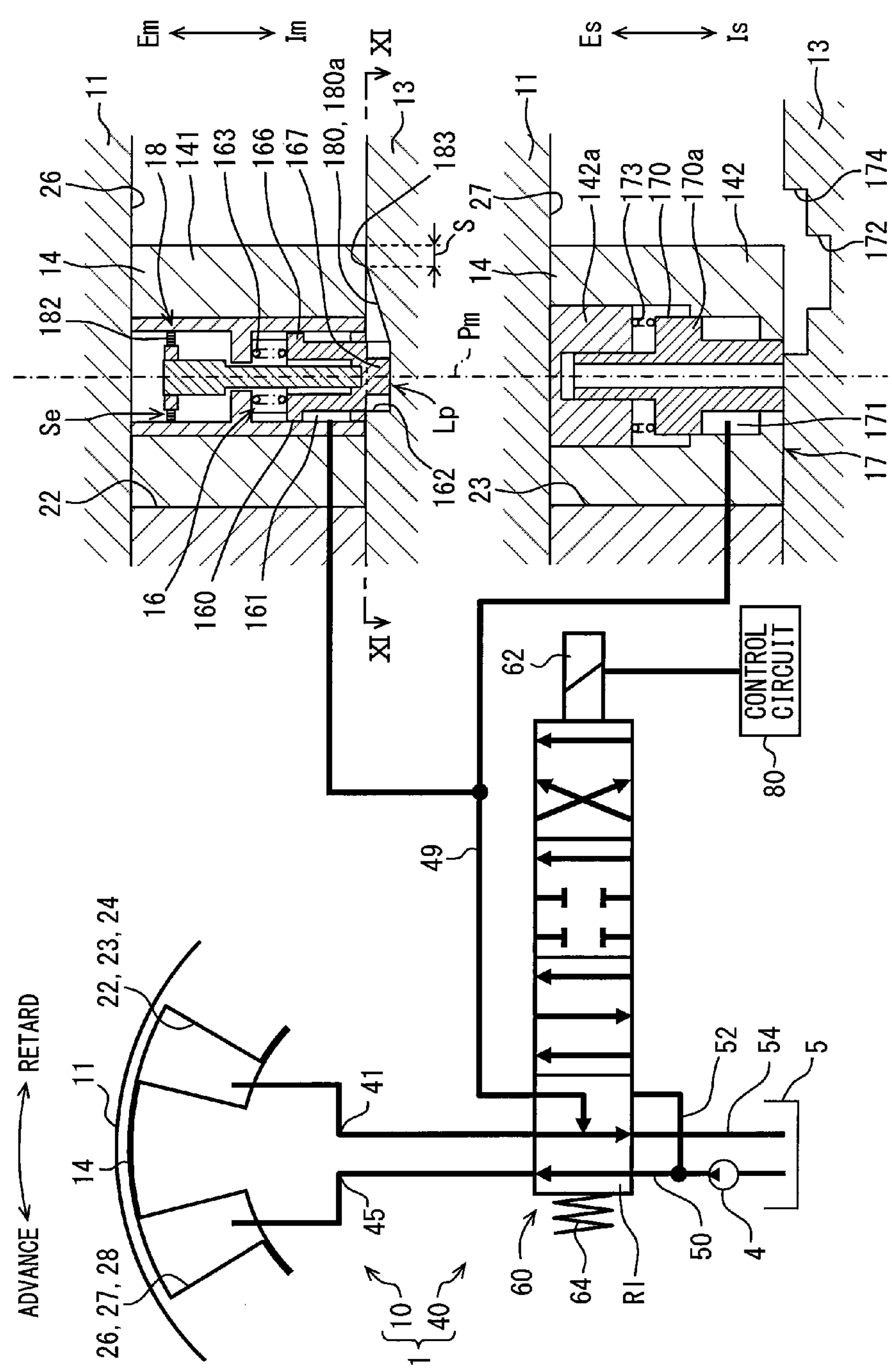


FIG. 6

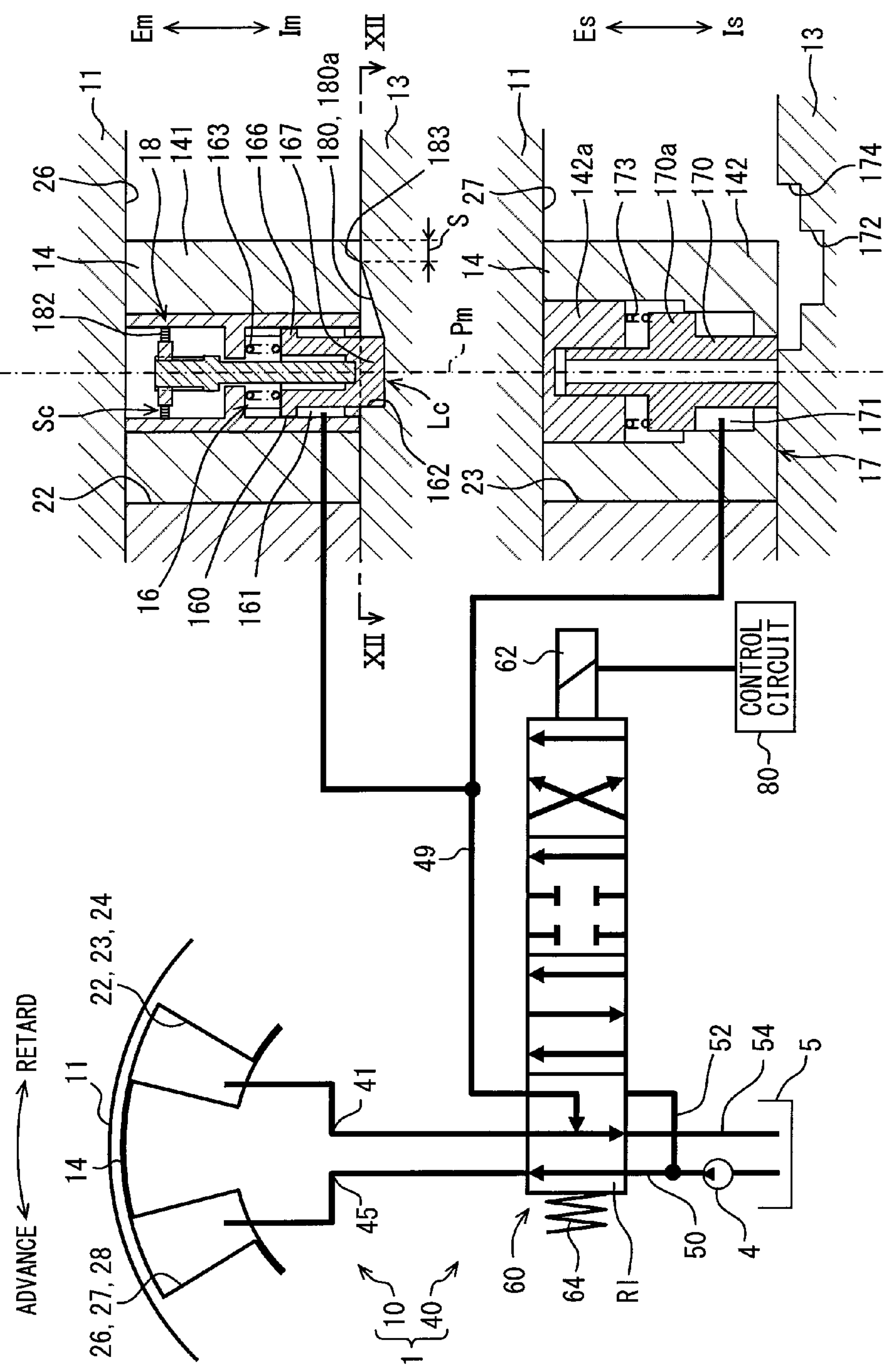


FIG. 7

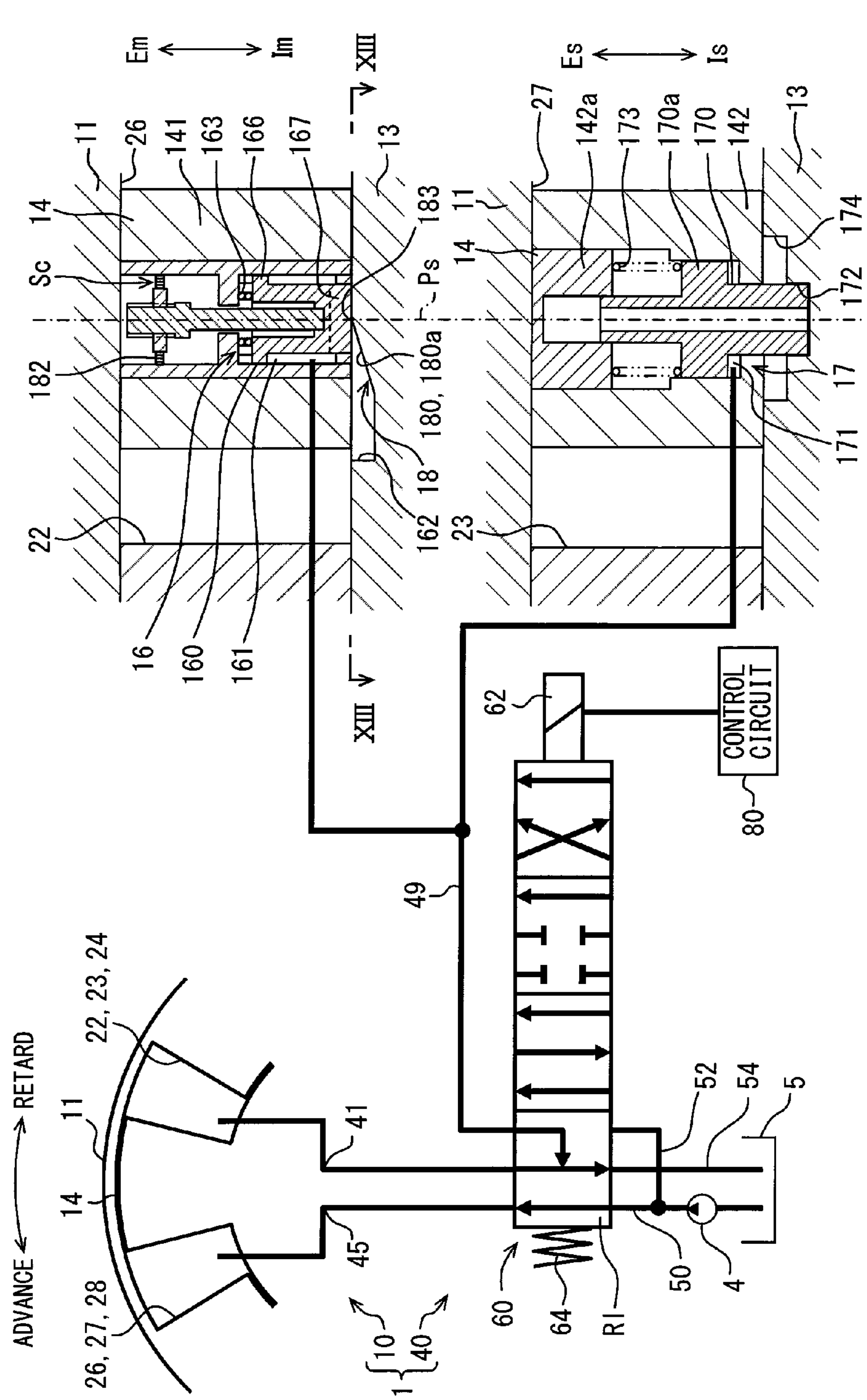


FIG. 8

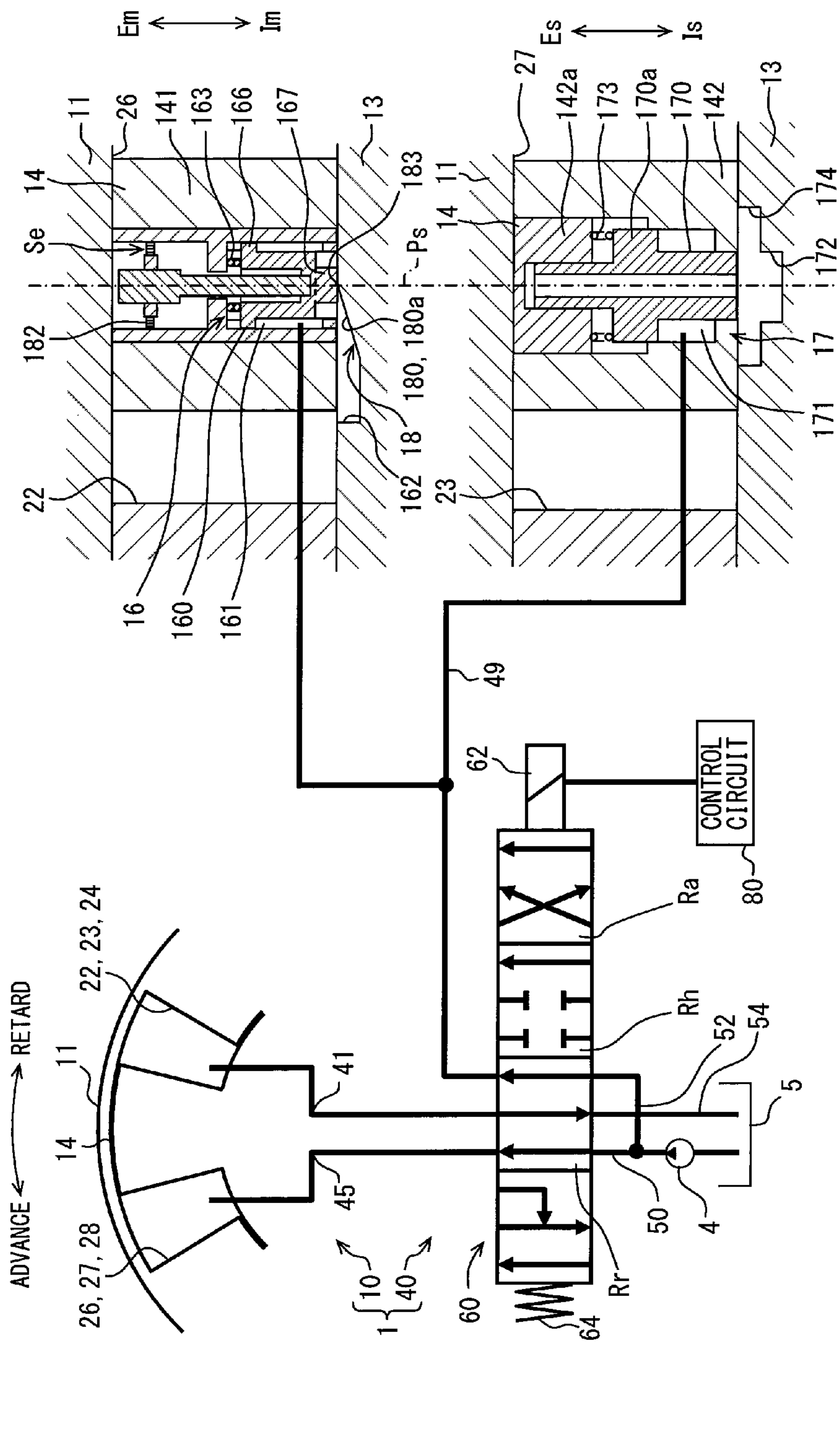
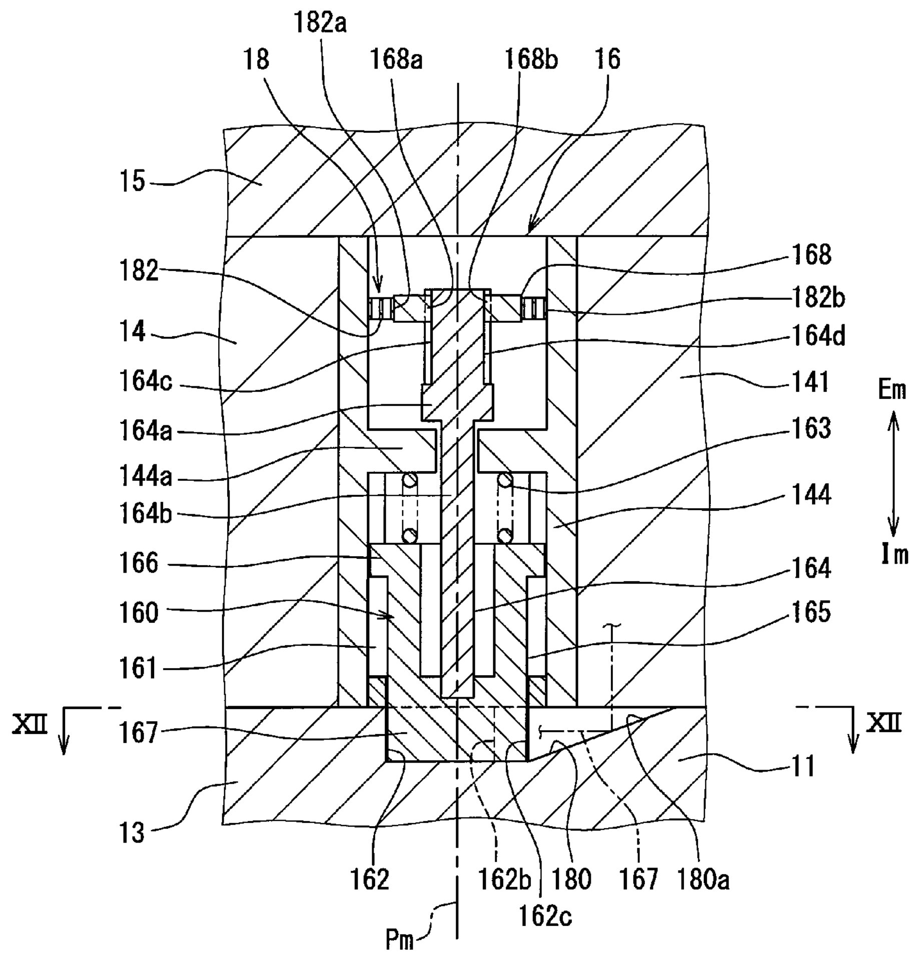

ADVANCE
RETARD
Em
Im
Es
Is
Se
Ps
CONTROL CIRCUIT
Ra
Rh
Rr
180, 180a
142a
170a
22, 23, 24
26, 27, 28

FIG. 9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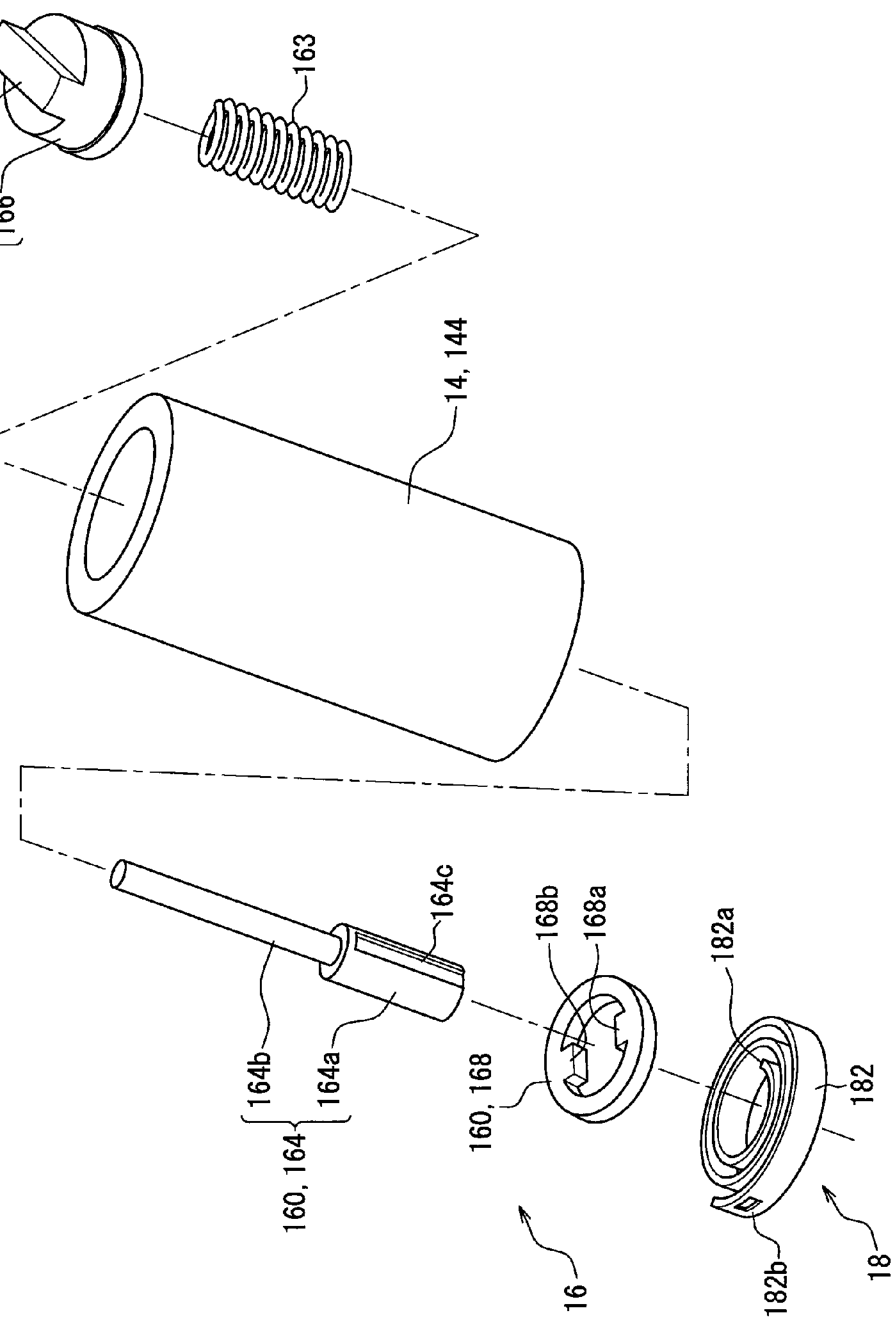
18
168a
168b
16
15
182
168
182b
14
164d
164c
141
Em
164a
163
144a
144
164b
Im
166
164
160
165
161
XII
XII
167
11
13
162
162b
180
167
180a
162c
Pm

FIG. 10


160, 165
167
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14, 144
164c
160, 164
164b
164a
168b
168a
160, 168
182a
182
182b
16
18

FIG. 11

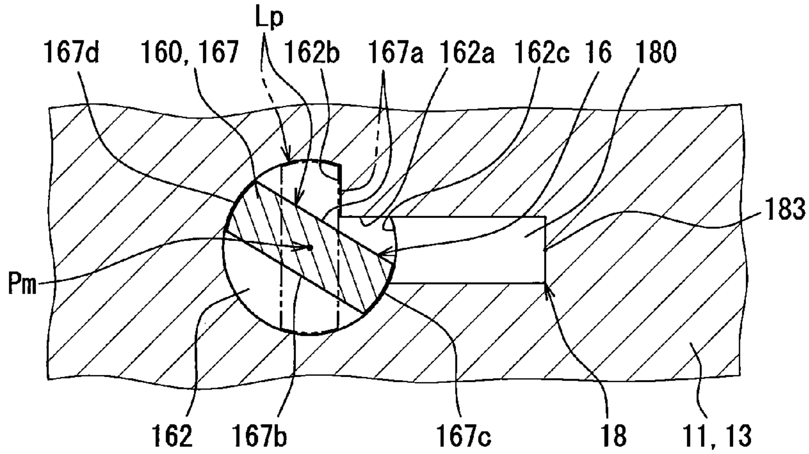


FIG. 12

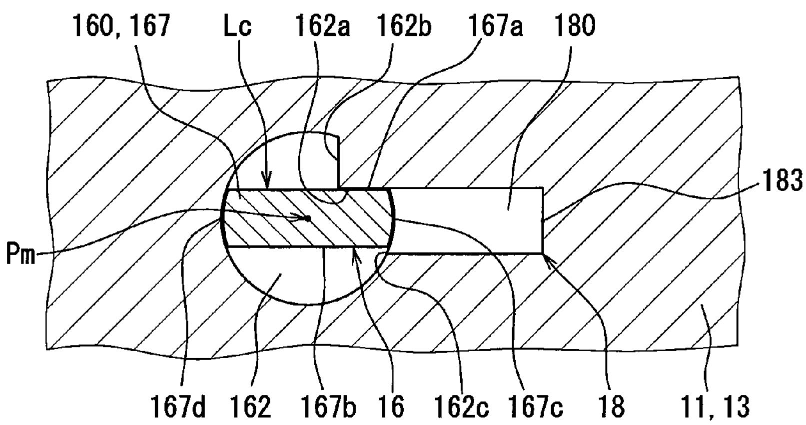


FIG. 13

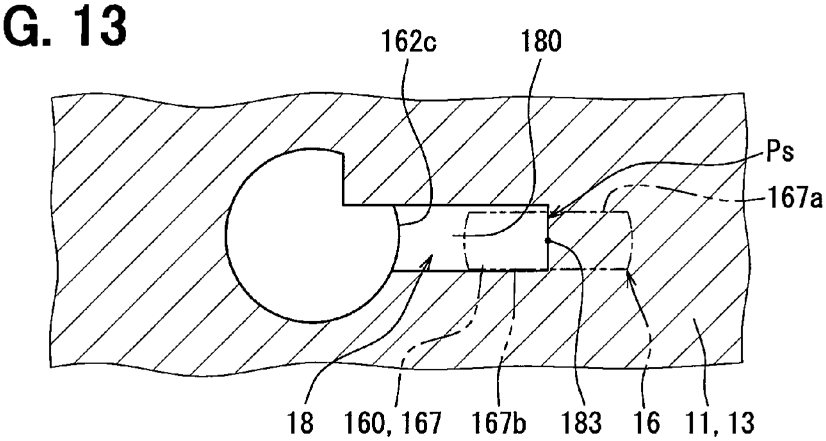


FIG. 14

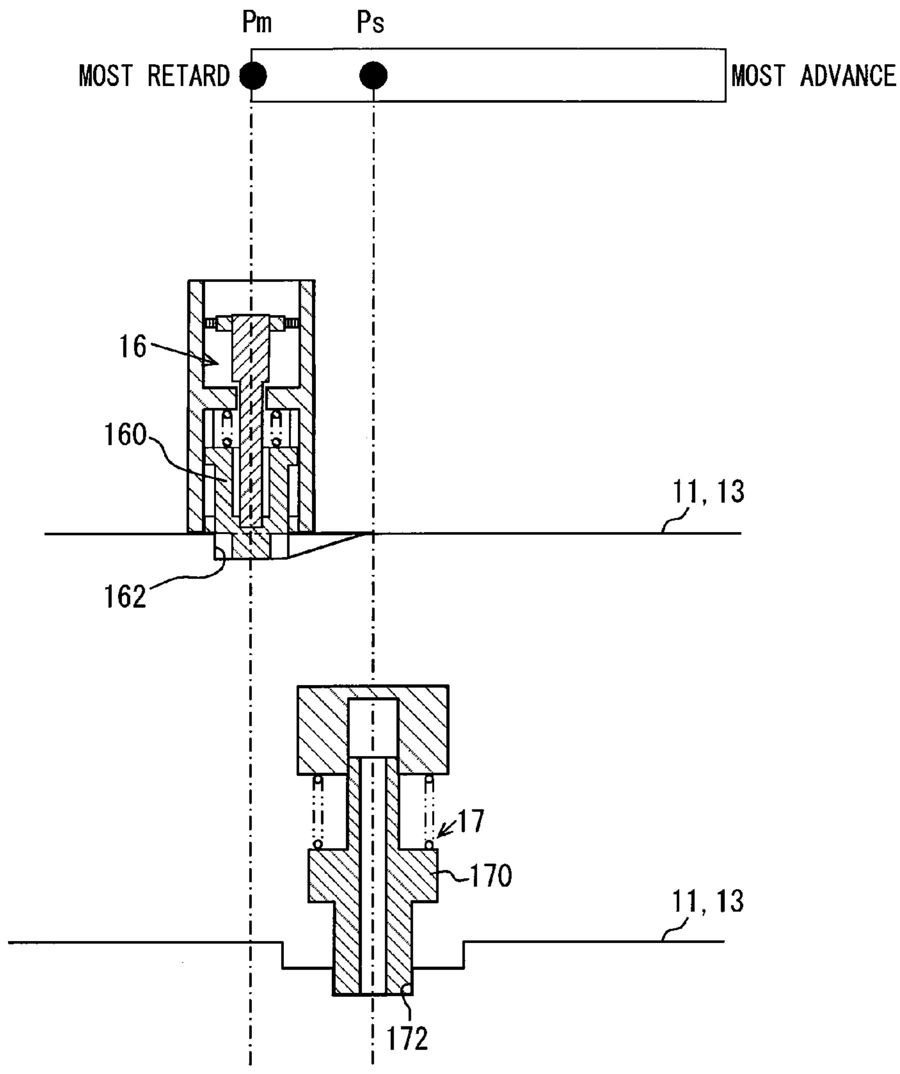
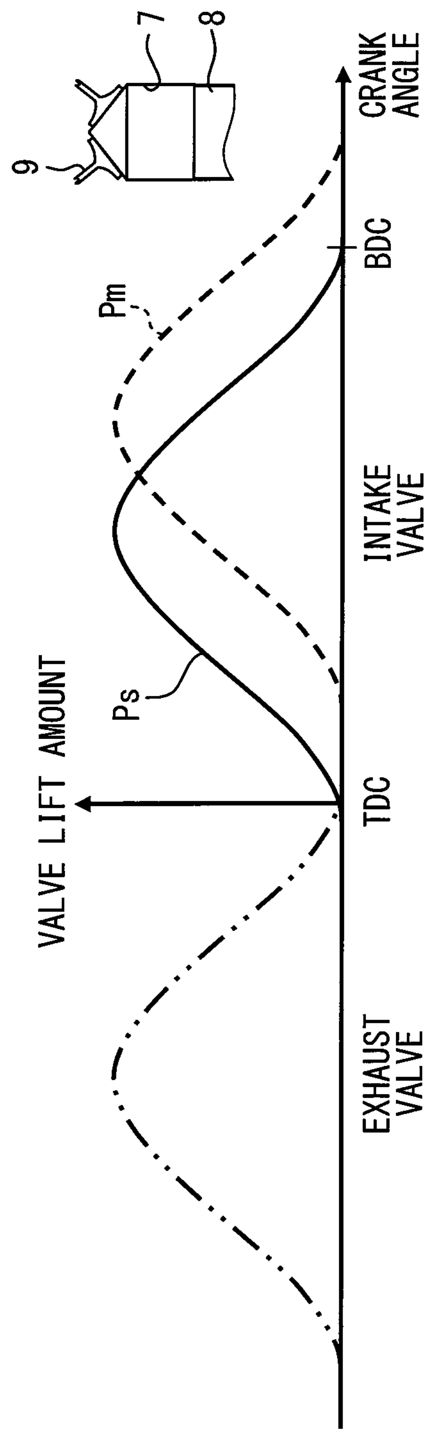


FIG. 15



VALVE LIFT AMOUNT
CRANK ANGLE
EXHAUST VALVE
TDC
INTAKE VALVE
BDC
Ps
Pm
7
8
9

FIG. 16

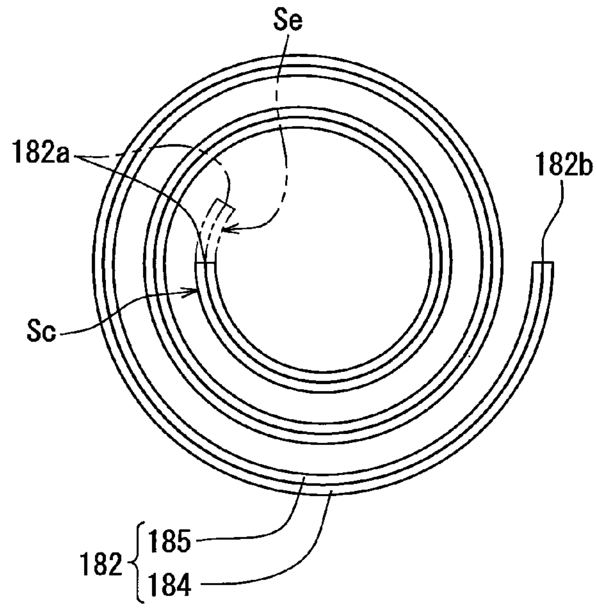

Se
182a
182b
Sc
182
185
184

FIG. 17

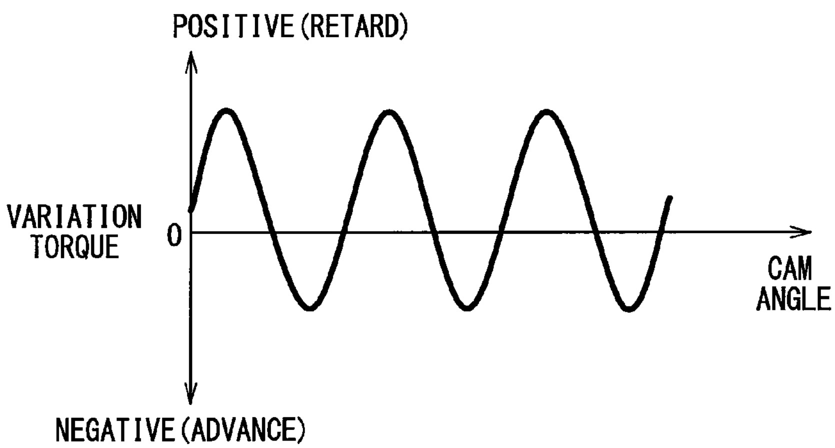
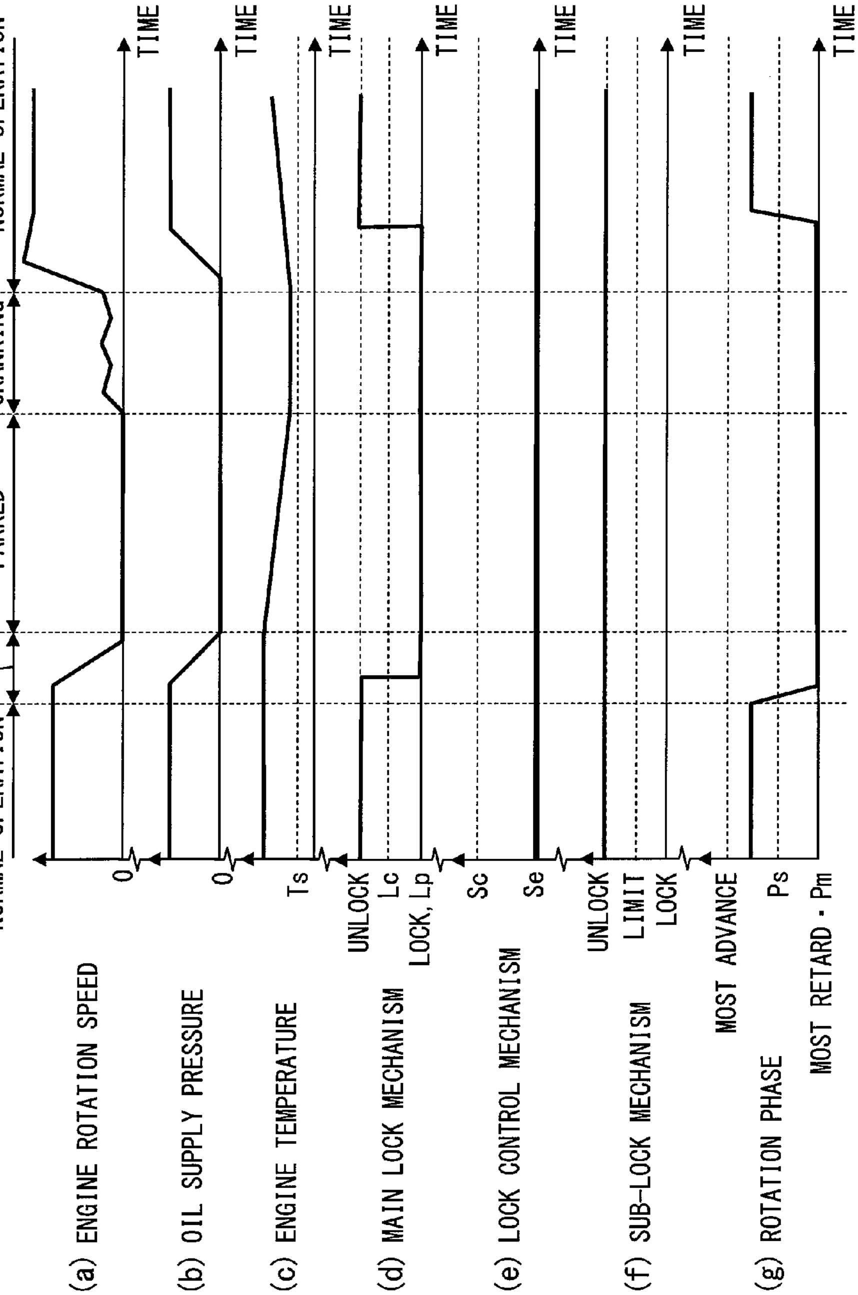

POSITIVE (RETARD)
VARIATION TORQUE
0
CAM ANGLE
NEGATIVE (ADVANCE)

FIG. 18



(a) ENGINE ROTATION SPEED
(b) OIL SUPPLY PRESSURE
(c) ENGINE TEMPERATURE
(d) MAIN LOCK MECHANISM
(e) LOCK CONTROL MECHANISM
(f) SUB-LOCK MECHANISM
(g) ROTATION PHASE
NORMAL OPERATION
STOP DIRECTIVE
STOP OPERATION
PARKED
START DIRECTIVE
CRANKING
PERFECT IGNITION
NORMAL OPERATION
0
0
Ts
UNLOCK
Lc
LOCK, Lp
Sc
Se
UNLOCK
LIMIT
LOCK
MOST ADVANCE
Ps
MOST RETARD・Pm
TIME
TIME
TIME
TIME
TIME
TIME
TIME

FIG. 19

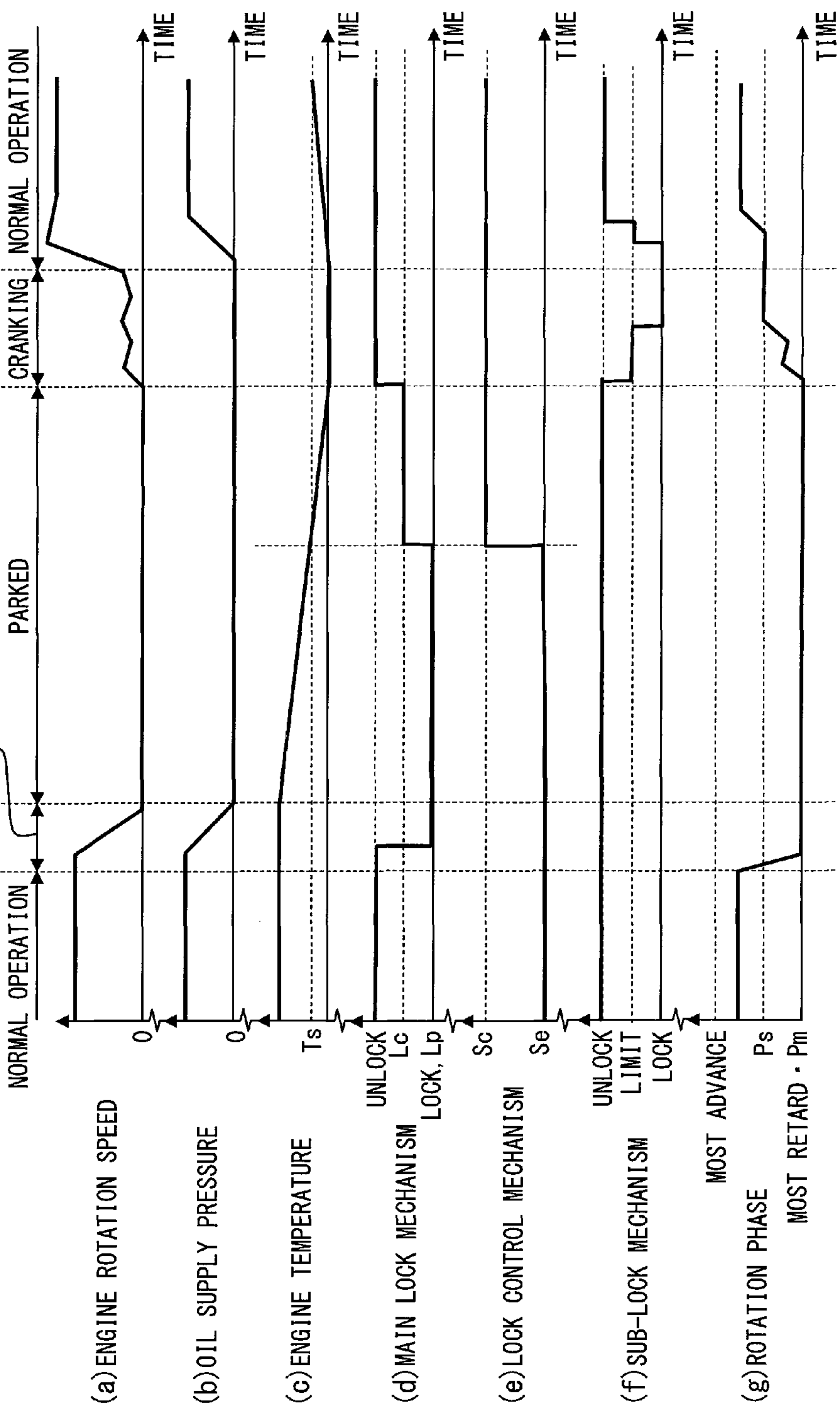
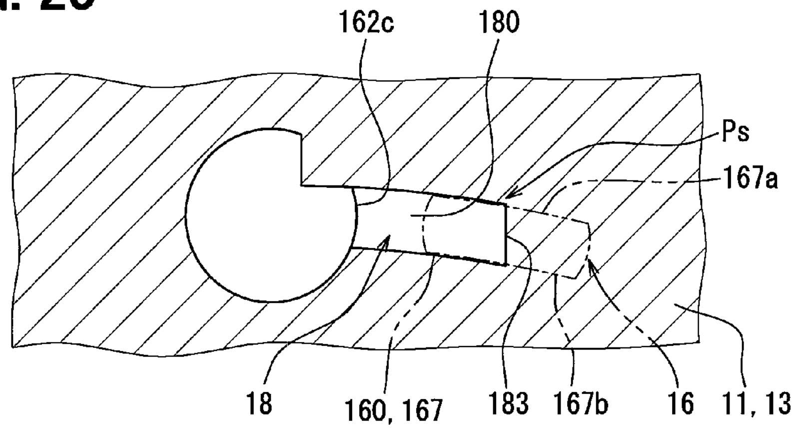

NORMAL OPERATION
STOP DIRECTIVE
STOP OPERATION
PARKED
START DIRECTIVE
CRANKING
PERFECT IGNITION
NORMAL OPERATION
(a)ENGINE ROTATION SPEED
(b)OIL SUPPLY PRESSURE
(c)ENGINE TEMPERATURE
(d)MAIN LOCK MECHANISM
(e)LOCK CONTROL MECHANISM
(f)SUB-LOCK MECHANISM
(g)ROTATION PHASE
0
0
Ts
UNLOCK
Lc
LOCK, Lp
Sc
Se
UNLOCK
LIMIT
LOCK
MOST ADVANCE
Ps
MOST RETARD・Pm
TIME

FIG. 20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167b
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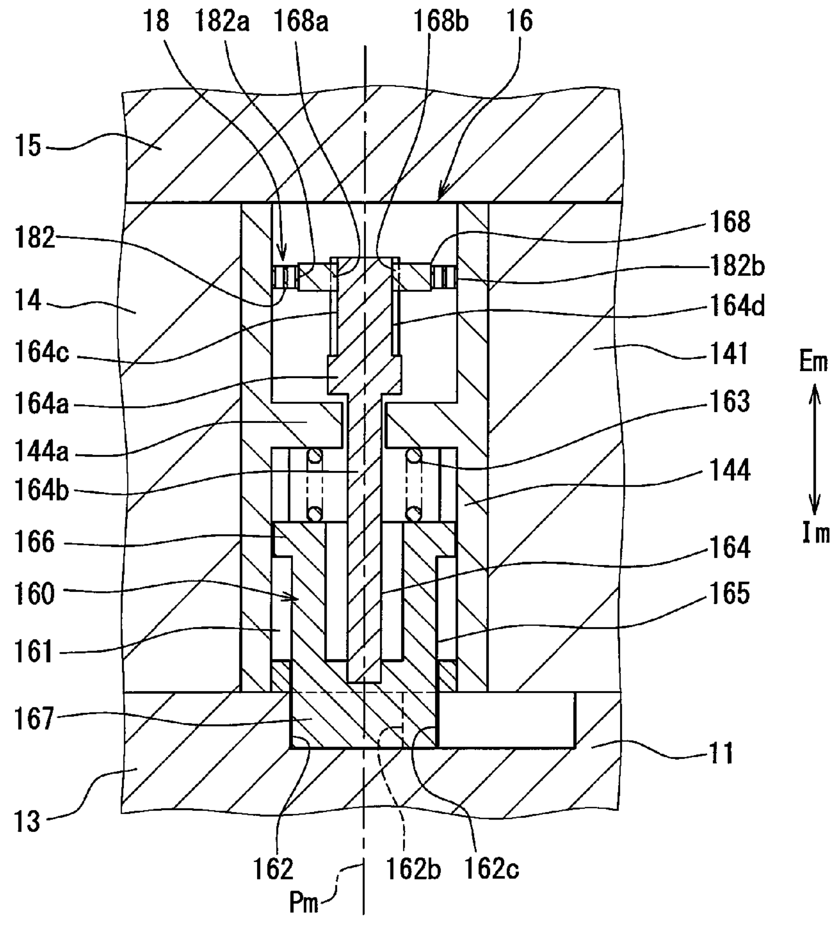
FIG. 21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167
11
13
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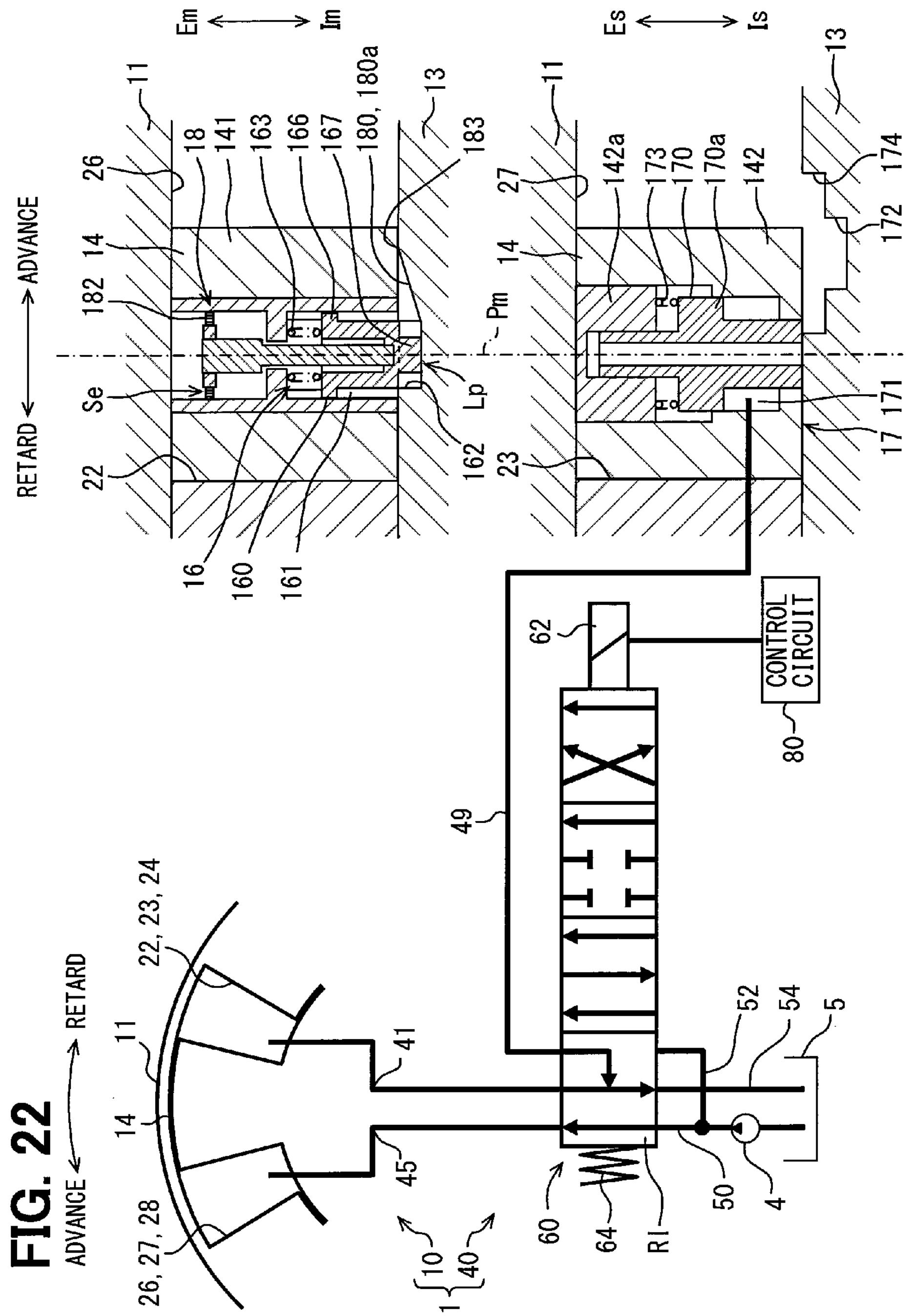
162b
162c
Pm

FIG. 22


ADVANCE
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54
49
62
CONTROL CIRCUIT
80
Em
Im
Es
Is
RETARD
ADVANCE
22
Se
182
18
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141
163
166
167
180, 180a
183
13
16
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161
162
Lp
Pm
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27
142a
173
170
170a
142
174
172
171
17

VALVE TIMING CONTROL APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Application No. 2013-81529 filed on Apr. 9, 2013, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to a valve timing control apparatus.

BACKGROUND

Conventionally, a fluid pressure type valve timing control apparatus is known, which controls a valve timing of an intake valve by a pressure of hydraulic fluid. Generally, the valve timing control apparatus is equipped with a housing rotor and a vane rotor which are rotated with a crankshaft and a camshaft of an internal combustion engine, respectively. The rotation phase between the rotors is changed when the vane rotor receives the pressure of hydraulic fluid in the housing rotor. The valve timing is adjusted by the change in the rotation phase.

JP 4161356 B describes such a valve timing control apparatus, in which the rotation phase is locked at a middle phase which is on the advance side from the most retard phase when the internal combustion engine is started. In this case, the timing closing an intake valve can be made early as much as possible, so a real compression ratio in a cylinder can be made high. Therefore, the temperature of gas in the cylinder is raised by heat produced by the compression, and the fuel evaporation is promoted. For example, under low temperature environment, the engine startability can be secured after the engine is left for a long time in the stop state.

However, the high compression ratio in the cylinder may cause knocking when the internal combustion engine is started under comparatively high temperature environment such as normal temperature.

Moreover, in case where the internal combustion engine is applied to an idling stop system or a hybrid system, when the engine is restarted, pre-ignition may be generated. Also, when the engine is restarted immediately after the engine is stopped by ignition-off, pre-ignition may be generated. The pre-ignition means a self-ignition before ignition when the temperature of gas in the cylinder becomes too much high at the time of compression. Moreover, if the variation in the cranking rotation is increased by a large reaction force of the compression, unpleasant vibration or noise is generated.

JP 2002-256910 A describes a fluid pressure type valve timing control apparatus, in which the lock phase is selected between a retard phase and a middle phase at the time of starting the internal combustion engine. The retard phase is set for closing an intake valve later than a timing at which the piston in a cylinder reaches a bottom dead center. The middle phase is on the advance side from the retard phase. Such a selection makes it possible to suitably start the engine based on the temperature of the engine (hereafter may be referred to engine temperature).

However, in JP 2002-256910 A, at the time of starting the engine under high temperature environment, the pressure of hydraulic fluid is applied to the vane rotor in the housing rotor, such that the retard phase is selected by the control in the rotation phase not by the lock of the rotation phase. Therefore, in case where the pressure of hydraulic fluid is low when the engine is started, the vane rotor is rotated on the advance side relative to the housing rotor by the variation torque applied from the camshaft, so the rotation phase is easily shifted from the retard phase.

Moreover, in JP 2002-256910 A, because the variation torque changes the rotation phase to the middle phase at the time of starting the engine under low temperature environment, the hydraulic fluid which gives pressure to the vane rotor in the housing rotor is drained. As a result, since the hydraulic fluid which gives pressure to a lock member is also drained, the lock member may move to an unlock position, so the lock at the middle phase may become difficult.

SUMMARY

According to an example of the present disclosure, a valve timing control apparatus which controls a valve timing of an intake valve opening and closing a cylinder of an internal combustion engine by a pressure of hydraulic fluid includes a housing rotor, a vane rotor, a main lock member, a secondary lock member, a lock controller. The housing rotor is rotated with a crankshaft of the internal combustion engine. The vane rotor is rotated with a camshaft of the internal combustion engine, and receives the pressure of hydraulic fluid in the housing rotor such that a rotation phase of the vane rotor relative to the housing rotor is changed. The main lock member has a main lock component and a main lock hole which are engaged with each other to lock the rotation phase at a main lock phase for closing the intake valve later than a timing at which a piston in the cylinder reaches a bottom dead center. The secondary lock member has a secondary lock component and a secondary lock hole which are engaged with each other to lock the rotation phase at a secondary lock phase which is set on an advance side than the main lock phase. The lock controller controls lock and unlock of the rotation phase by controlling the main lock member and the secondary lock member, and has a guide slot and a temperature sensing member. The guide slot guides the main lock component from the main lock hole toward a permission point at which the secondary lock component is allowed to enter the secondary lock hole at the secondary lock phase. The temperature sensing member expands at the main lock phase when a temperature of the engine is higher than or equal to a predetermined temperature so as to prohibit the main lock component from moving out of the main lock hole toward the guide slot. The temperature sensing member shrinks at the main lock phase when the temperature of the engine is lower than the predetermined temperature so as to allow the main lock component to move out of the main lock hole toward the guide slot.

Accordingly, when the temperature of the engine is higher than or equal to the predetermined temperature in the state where the engine is stopped, at the main lock phase, the temperature sensing member expands such that the main lock component is prohibited from moving out of the main lock hole toward the guide slot. As a result, the main lock component stays at the main lock hole, and the rotation phase maintains to be locked at the main lock phase. At the main lock phase, the intake valve is closed later timing later than the timing at which the piston in the cylinder reaches the bottom dead center, therefore, at the next start of the engine, gas in the cylinder is pushed out to the intake system by the lift-up of the piston after reaching the bottom dead center. Thus, a real compression ratio is lowered. Accordingly, when the temperature of the engine is higher than or equal to the predetermined temperature and when the engine is started, the rotation phase is maintained to be locked at the main lock phase, so starting fault such as knocking, pre-ignition and unpleasant vibration or noise can be controlled.

On the other hand, when the temperature of the engine is lower than the predetermined temperature in the state where the engine is stopped, at the main lock phase, the rotation phase is unlocked by the temperature sensing member because the main lock component is allowed to move. Therefore, at the next start of the engine, the main lock component is guided toward the permission point from the main lock hole to the guide slot by the variation torque applied from the camshaft, and the vane rotor is rotated on the advance side relative to the housing rotor. As a result, when the rotation phase is changed to the secondary lock phase which is set on the advance side than the main lock phase, the secondary lock component is allowed to fit to the secondary lock hole, and the rotation phase is locked at the secondary lock phase. Therefore, the timing at which the intake valve is closed can be made early as much as possible. Thus, the push-out amount of the gas in the cylinder decreases, and the temperature of the gas is raised with the real compression ratio. Accordingly, the ignitionability is raised to secure the startablity even if the temperature of the engine is low when the engine is started.

Accordingly, it becomes possible to realize the engine start suitable for the engine temperature.

For example, the main lock component is able to rotate in a circumferential direction of the main lock hole between a prohibition position where the main lock component is prohibited from moving out at the main lock phase and an allowance position where the main lock component is allowed to move out at the main lock phase. The temperature sensing member is changed based on the temperature of the engine between an expanding state in which the main lock component is driven to rotate to the prohibition position and a shrinking state in which the main lock component is driven to rotate to the allowance position.

Accordingly, when the temperature of the engine is higher than or equal to the predetermined temperature in the state where the engine is stopped, at the main lock phase, the main lock component is rotated to the prohibition position in the circumferential direction of the main lock hole, and is prohibited from moving toward the guide slot by the expanding of the temperature sensing member. In this way, the rotation phase is maintained to be locked at the main lock phase, and the starting fault may be controlled.

On the other hand, when the temperature of the engine is lower than the predetermined temperature in the state where the engine is stopped, at the main lock phase, the lock component is rotated to the allowance position in the circumferential direction of the main lock hole, and is allowed to move to the guide slot by the shrinking of the temperature sensing member. In this way, the rotation phase is changed by the variation torque to the secondary lock phase, so the startability may be secured.

Accordingly, the rotation phase can be suitably changed by the expanding and the shrinking of the temperature sensing member based on the temperature of the engine and the rotation of the main lock component.

For example, the guide slot is defined at a predetermined position of the main lock hole in the circumferential direction. The main lock component has a slide part which rotatably enters the main lock hole at the main lock phase and which slides into the guide slot at the rotation phase from the main lock phase to the secondary lock phase. The prohibition position is a rotation position where the slide part is deviated from an opening of the main lock hole corresponding to the guide slot in the circumferential direction of the main lock hole. The allowance position is a rotation position where the slide part is able to enter the opening of the main lock hole corresponding to the guide slot.

Accordingly, the slide part of the main lock component entering the main lock hole at the main lock phase when the temperature of the engine is high while the engine is in the stopped condition is rotated to the prohibition position by the temperature sensing member in the expanding state, thereby producing a circumferential deviation relative to the opening corresponding to the guide slot at a predetermined position in the circumferential direction. Therefore, the slide part is certainly prohibited from moving out of the main lock hole toward the guide slot, and the rotation phase can be maintained to be locked at the main lock phase.

On the other hand, the slide part entering the main lock hole at the main lock phase at the main lock phase when the temperature of the engine is low while the engine is in the stopped condition is rotated to the allowance position by the temperature sensing member in the shrinking state, thereby opposing the guide slot to be able to enter the opening. Therefore, the slide part is certainly allowed to move out of the main lock hole to the guide slot, and the rotation phase can be unlocked from the main lock phase.

Furthermore, when the rotation phase is changed to the secondary lock phase while the temperature of the engine is low under the situation where the engine is in the stopped condition, the slide part slides in the guide slot, therefore, the main lock component can be certainly guided to the permission point, and the secondary lock component is made to enter the secondary lock hole. Thus, the rotation phase is correctly and accurately locked or unlocked based on the engine temperature, and it becomes possible to improve the reliability about the change in the rotation phase suitably based on the temperature of the engine in the stopped state.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

FIG. **1** is a schematic cross-sectional view illustrating a valve timing control apparatus according to a first embodiment, taken along a line I-I of FIG. **2**;

FIG. **2** is a cross-sectional view taken along a line II-II of FIG. **1**;

FIG. **3** is a cross-sectional view illustrating an operation state different from FIG. **2**;

FIG. **4** is a cross-sectional view taken along a line IV-IV of FIG. **3**;

FIG. **5** is a diagram showing an operation state of the valve timing control apparatus of FIG. **1**;

FIG. **6** is a diagram showing an operation state of the valve timing control apparatus of FIG. **1**;

FIG. **7** is a diagram showing an operation state of the valve timing control apparatus of FIG. **1**;

FIG. **8** is a diagram showing an operation state of the valve timing control apparatus of FIG. **1**;

FIG. **9** is an enlarge view illustrating a part of the valve timing control apparatus of FIG. **1**;

FIG. **10** is an exploded perspective view illustrating the valve timing control apparatus of FIG. **1**;

FIG. **11** is a cross-sectional view taken along a line XI-XI of FIG. **5**;

FIG. **12** is a cross-sectional view taken along a line XII-XII of FIGS. **6** and **9**;

FIG. **13** is a cross-sectional view taken along a line XIII-XIII of FIG. **7**;

FIG. **14** is a diagram for explaining a feature of the valve timing control apparatus of FIG. **1**;

FIG. **15** is a characteristic diagram for explaining a feature of the valve timing control apparatus of FIG. **1**;

FIG. **16** is a plan view illustrating a temperature sensor of the valve timing control apparatus of FIG. **1**;

FIG. **17** is a graph for explaining a variation torque applied to the valve timing control apparatus of FIG. **1**;

FIG. **18** is a time chart for explaining an operation example of the valve timing control apparatus of FIG. **1**;

FIG. **19** is a time chart for explaining an operation example of the valve timing control apparatus of FIG. **1**;

FIG. **20** is a modification example of FIG. **13**;

FIG. **21** is a modification example of FIG. **9**; and

FIG. **22** is a modification example of FIG. **5**.

DETAILED DESCRIPTION

An embodiment of the present disclosure is described based on the drawings.

As shown in FIG. **1**, a valve timing control apparatus **1** according to the embodiment is mounted to an internal combustion engine of a vehicle. In this embodiment, the engine is stopped and started not only by OFF instruction and ON instruction of an engine switch SW, respectively, but also by idling stop instruction and re-starting instruction of an idling stop (reduction) system ISS.

The valve timing control apparatus **1** is a fluid pressure type which uses a pressure of operation oil (hydraulic fluid), and adjusts a valve timing of an intake valve **9** (see FIG. **15**) which is opened or closed by a camshaft **2** by transmitting the engine torque. As shown in FIGS. **1-8**, the valve timing control apparatus **1** is equipped with a drive part **10** and a control part **40**. The drive part **10** is arranged in a transfer system which transmits the engine torque outputted from a crankshaft (not shown) of the engine to the camshaft **2**. The control part **40** controls a flow of the operation oil to drive the drive part **10**.

As shown in FIGS. **1** and **2**, the drive part **10** has a housing rotor **11** made of metal, in which a rear plate **13** and a front plate **15** are tightened to the axial ends of a shoe ring **12**, respectively. The rear plate **13** has lock holes **162**, **172** opposing to the shoe ring **12**.

The shoe ring **12** has a cylindrical main housing **120**, multiple shoes **121**, **122**, **123**, and a sprocket **124**. As shown in FIG. **2**, the shoes **121**, **122**, **123** are arranged in the rotational direction with a predetermined interval, and are projected inward in the radial direction from the main housing **120**. An accommodation chamber **20** is defined between the shoes **121**, **122**, **123** adjacent with each other. The sprocket **124** is connected to the crankshaft through a timing chain (not shown). While the engine is rotated, the engine torque is transmitted to the sprocket **124** from the crankshaft, such that the housing rotor **11** is rotated with the crankshaft in a predetermined direction (clockwise in FIG. **2**).

As shown in FIGS. **1** and **2**, a vane rotor **14** made of metal is coaxially accommodated in the housing rotor **11**. The axial ends of the vane rotor **14** are slidingly moved on the rear plate **13** and the front plate **15**, respectively. The vane rotor **14** has a cylindrical rotation shaft **140** and multiple vanes **141**, **142**, **143**. The rotation shaft **140** is coaxially fixed to the camshaft **2**. The vane rotor **14** is rotated with the camshaft **2** in the same direction as the housing rotor **11** (clockwise in FIG. **2**), and is able to be rotated relative to the housing rotor **11**.

As shown in FIG. **2**, the vanes **141**, **142**, **143** are arranged in the rotational direction with a predetermined interval, and are projected outward in the radial direction from the rotation shaft **140** so as to be accommodated in the corresponding accommodation chambers **20**, respectively. The vane **141**, **142**, **143** divides the corresponding accommodation chamber **20** into two spaces in the rotation direction, such that advance chambers **22**, **23**, **24** and retard chambers **26**, **27**, **28** are defined in the housing rotor **11** for the operation oil. Specifically, the advance chamber **22** is formed between the shoe **121** and the vane **141**, the advance chamber **23** is formed between the shoe **122** and the vane **142**, and the advance chamber **24** is formed between the shoe **123** and the vane **143**. The retard chamber **26** is formed between the shoe **122** and the vane **141**, the retard chamber **27** is formed between the shoe **123** and the vane **142**, and the retard chamber **28** is formed between the shoe **121** and the vane **143**.

As shown in FIGS. **1** and **2**, the vane **141** supports a main lock component **160** made of metal in a state where the main lock component **160** is able to reciprocate in the axial direction at an eccentric position relative to the rotation shaft **140**. The vane **141** has an annular main unlock chamber **161** around the main lock component **160** for the operation oil. As shown in FIGS. **1** and **5**, when the operation oil is discharged from the main unlock chamber **161**, the main lock component **160** moves and fits to the main lock hole **162**. The main lock component **160** locks a rotation phase of the vane rotor **14** relative to the housing rotor **11** (hereafter may be just referred to the rotation phase) at a main lock phase Pm. In contrast, as shown in FIGS. **7** and **8**, the main lock component **160** moves out of the main lock hole **162** by receiving the pressure of the operation oil introduced into the main unlock chamber **161**. Thus, the main lock component **160** unlocks the rotation phase from the main lock phase Pm.

As shown in FIGS. **3** and **4**, the vane **142** supports a secondary lock component **170** made of metal in a state where the secondary lock component **170** is able to reciprocate in the axial direction at an eccentric position relative to the rotation shaft **140**. The vane **142** has an annular secondary unlock chamber **171** around the secondary lock component **170** for the operation oil. As shown in FIGS. **4** and **7**, when the operation oil is discharged from the secondary unlock chamber **171**, the secondary lock component **170** moves and fits to the secondary lock hole **172**. Thus, the secondary lock component **170** locks the rotation phase at a secondary lock phase Ps. In contrast, as shown in FIG. **8**, the secondary lock component **170** moves out of the secondary lock hole **172** by receiving the pressure of the operation oil introduced into the secondary unlock chamber **171**. Thus, the secondary lock component **170** unlocks the rotation phase from the secondary lock phase Ps.

In the drive part **10**, under the situation where the rotation phase is unlocked, the vane rotor **14** receives the pressure of the operation oil flowing into or from the advance chambers **22**, **23**, **24** and the retard chambers **26**, **27**, **28** in the housing rotor **11**, such that the valve timing is adjusted. Specifically, when the operation oil is introduced to the advance chambers **22**, **23**, **24** and when the operation oil is discharged from the retard chambers **26**, **27**, **28**, the rotation phase changes to the advance side (for example, from FIG. **2** to FIG. **3**). As a result, the valve timing is advanced.

When the operation oil is introduced to the retard chambers **26**, **27**, **28** and when the operation oil is discharged from the advance chambers **22**, **23**, **24**, the rotation phase changes to the retard side (for example, from FIG. **3** to FIG. **2**). As a result, the valve timing is retarded. When the operation oil stays in the advance chambers **22**, **23**, **24** and the retard chambers **26**, **27**, **28**, the rotation phase is restricted from changing, and the valve timing is approximately maintained.

In the control part **40**, as shown in FIGS. **1** and **5**, a main advance passage **41** is defined in the rotation shaft **140**, and communicates to the advance chambers **22**, **23**, **24**. A main retard passage **45** is defined in the rotation shaft **140**, and communicates to the retard chambers **26**, **27**, **28**. An unlock passage **49** is defined in the rotation shaft **140**, and communicates to both of the unlock chambers **161**, **171**.

A main supply passage **50** is defined in the rotation shaft **140**, and communicates to a pump **4** corresponding to a supply source through a conveyance passage **3**. The pump **4** is a mechanical type driven by receiving the engine torque while the engine is rotated, and continues discharging the operation oil taken from a drain pan **5** during the rotation of the engine. The conveyance passage **3** passing through the camshaft **2** and the bearing is always able to communicate with the discharge port of the pump **4** irrespective of the rotation of the camshaft **2**. When the engine is cranked to start and perfect ignition, the supply of operation oil to the main supply passage **50** is started. The supply of operation oil is stopped when the engine stops.

A sub supply passage **52** is defined in the rotation shaft **140**, and is branched from the main supply passage **50**. The sub supply passage **52** receives the operation oil supplied from the pump **4** through the main supply passage **50**. A drain recovering passage **54** is defined outside the drive part **10** and the camshaft **2**. The drain recovering passage **54** is defined outside atmosphere with the drain pan **5** as a drain recovering section, and is able to discharge the operation oil to the drain pan **5**.

A control valve **60** is a spool valve, and uses the driving force generated by a linear solenoid **62** and the restoring force of a biasing component **64** which is generated in the opposite direction opposite from the driving force. The control valve **60** is connected with each of the passages **41**, **45**, **49**, **50**, **52**, **54**, and makes a spool **68** to reciprocate in a sleeve **66** in the axial direction, as shown in FIGS. **1** and **2**, thereby changing the communication or interception state between the passages. Specifically, when the spool **68** moves to a lock domain Rl shown in FIGS. **5**-**7**, the operation oil is introduced from the pump **4** into the retard chambers **26**, **27**, **28**, and the operation oil is discharged from the advance chambers **22**, **23**, **24** and the unlock chamber **161**, **171** to the drain pan **5**.

When the spool **68** moves to a retard domain Rr shown in FIG. **8**, the operation oil is discharged from the advance chambers **22**, **23**, **24** to the drain pan **5**, and the operation oil is introduced from the pump **4** into the retard chambers **26**, **27**, **28** and the unlock chamber **161**, **171**. When the spool **68** moves to an advance domain Ra shown in FIG. **8**, the operation oil is discharged from the retard chambers **26**, **27**, **28** to the drain pan **5**, and the operation oil is introduced from the pump **4** into the advance chambers **22**, **23**, **24** and the unlock chamber **161**, **171**. When the spool **68** moves to a hold domain Rh shown in FIG. **8**, the operation oil is introduced from the pump **4** into the unlock chamber **161**, **171**, and the operation oil stays in the advance chambers **22**, **23**, **24** and the retard chambers **26**, **27**, **28**.

A control circuit **80** is a microcomputer electrically connected with the linear solenoid **62**, the engine switch SW and the various electronic parts of the engine, so as to construct the idling stop system ISS. The control circuit **80** controls the energization of the linear solenoid **62** and the operation of the engine including the idol stop according to a computer program.

A main lock mechanism **16** corresponding to a main lock member is described. As shown in FIGS. **1**, **2**, **9**, and **10**, the main lock mechanism **16** is defined by combining a main elastic component **163** to the group of the main lock elements **160**, **161**, **162**.

As shown in FIGS. **9** and **12**, the main lock hole **162** defined in the rear plate **13** to have a based (blind) cylindrical hole has a prohibition stopper **162***b*, an allowance stopper **162***a*, and an opening **162***c* arranged in this order in the circumferential direction. The allowance stopper **162***a* and the prohibition stopper **162***b* have plane shapes approximately perpendicular to each other, in other words, the stoppers **162***a*, **162***b* face in the opposite direction from each other in the circumferential direction of the main lock hole **162**. The opening **162***c* has a predetermined dimension at a specific position adjacent to the allowance stopper **162***a*, that is opposite from the prohibition stopper **162***b* in the circumferential direction of the main lock hole **162**. The opening **162***c* corresponds to an opening of a guide slot **180** to be explained later. The guide slot **180** may be referred as a guide groove.

As shown in FIGS. **9** and **10**, the main lock component **160** is inserted into a cylindrical support bush **144** disposed in the vane **141** of the vane rotor **14** in the integrally rotatable state. The main lock component **160** coaxially has a shaft **164**, a plunger **165**, and a fitting ring **168** relative to the support bush **144**.

The shaft **164** has a large diameter part **164***a* and a small diameter part **164***b*. A diameter of the large diameter part **164***a* is larger than that of the small diameter part **164***b*. The small diameter part **164***b* is projected from the large diameter part **164***a*. As shown in FIG. **9**, the support bush **144** has an inner flange part **144***a* at the intermediate position in the axial direction, and the large diameter part **164***a* is located between the inner flange part **144***a* and the front plate **15**. The large diameter part **164***a* is able to reciprocate in the axial direction and is able to rotate in the circumferential direction, in the support bush **144**. The small diameter part **164***b* passes through a main hole of the inner flange part **144***a*, that is, extends from a side of the front plate **15** through the flange part **144***a* to a side of the rear plate **13**. The small diameter part **164***b* is projected toward the rear plate **13** from the large diameter part **164***a*, and is able to reciprocate and rotate integrally with the large diameter part **164***a*.

As shown in FIGS. **9** and **10**, the plunger **165** includes a cylindrical slide part **166** and a plate slide part **167**. The cylindrical slide part **166** has a cylindrical shape with a base. The plate slide part **167** is projected from the base of the cylindrical slide part **166** in the axial direction. As shown in FIG. **9**, the cylindrical slide part **166** is located between the inner flange part **144***a* and the rear plate **13**, and is able to reciprocate in the axial direction and is able to rotate in the circumferential direction, in the support bush **144**. An end part of the small diameter part **164***b* of the shaft **164** is fittingly fixed to the base of the cylindrical slide part **166**.

The cylindrical slide part **166** is slidingly supported by the inner circumference part of the support bush **144**, and is guided with the shaft **164** in the axial direction. The cylindrical slide part **166** is exposed to the main unlock chamber **161**, and receives the pressure from the unlock chamber **161**. At the main lock phase Pm shown in FIGS. **5** and **6**, the cylindrical slide part **166** is coaxially arranged as the main lock hole **162**, and is defined to have an axial direction, a radial direction, and a circumferential direction in common with the main lock hole **162**. At the main lock phase Pm, in this embodiment, the cylindrical slide part **166** does not enter the main lock hole **162** at a position in the axial direction.

As shown in FIG. **9**, the plate slide part **167** is projected toward the rear plate **13** from the cylindrical slide part **166** in the support bush **144**, thereby, is able to reciprocate and rotate integrally with the cylindrical slide part **166**. As shown in FIG. **12**, the plate slide part **167** has a pair of long surfaces **167***a*, **167***b* and a pair of short surfaces **167***c*, **167***d* to define a width-across-flat portion. The pair of long surfaces **167***a*, **167***b* defines a width portion of the plate slid part **167**, which is able to enter the opening **162***c*. The long surface **167***a*, **167***b* spreads with a plane shape parallel along with the axial direction and the radial direction of the cylindrical slide part **166**. The short surface **167***c*, **167***d* connects the edges of the long surfaces **167***a*, **167***b* with each other in the curved shape.

At the main lock phase Pm shown in FIGS. **5**, **6**, **11**, and **12**, the plate slide part **167** is able to rotate in the circumferential direction of the main lock hole **162** between an allowance position Lc shown in FIG. **12** and a prohibition positions Lp shown in FIG. **11** in the state where the plate slide part **167** is located in the main lock hole **162**. Specifically, at the allowance position Lc shown in FIG. **12**, the short surface **167***c* of the plate slide part **167** opposes to enter the opening **162***c*, and the long surface **167***a* is in contact with the allowance stopper **162***a*.

At the prohibition position Lp shown in FIG. **11**, the short surface **167***c* of the plate slide part **167** is deviated in the circumferential direction relative to the opening **162***c*, and both the short surfaces **167***c*, **167***d* are fitted to the inner circumference part of the main lock hole **162** between the opening **162***c* and the prohibition stopper **162***b*.

In this embodiment, the prohibition position Lp is set in a range of about ¾ of the circumference. In other words, the prohibition position Lp extends in the circumferential direction (clockwise in FIG. **11**) from the allowance position Lc to a position at which the long surface **167***a* is in contact with the prohibition stopper **162***b* (as shown in a double chain line of FIG. **11**). Thus, at the prohibition position Lp, the plate slide part **167** is prohibited from entering the opening **162***c*, so the plate slide part **167** cannot move out of the main lock hole **162** into the guide slot **180**. In contrast, at the allowance position Lc, the plate slide part **167** is able to move out of the main lock hole **162** into the guide slot **180**.

As shown in FIG. **9**, the fitting ring **168** is arranged to surround the large diameter part **164***a*, and is located between the front plate **15** and the inner flange part **144***a*. The fitting ring **168** is able to rotate in the circumferential direction under the situation where the axial movement is regulated by the temperature sensing member **182** in the support bush **144**. As shown in FIGS. **9** and **10**, the fitting ring **168** integrally has a pair of fitting projections **168***a*, **168***b* projected inward in the radial direction, on the inner circumference part. The outer circumference part of the large diameter part **164***a* has slide grooves **164***c*, **164***d* extended in the axial direction. The fitting projections **168***a*, **168***b* are slidingly fitted to the slide grooves **164***c*, **164***d*, respectively. Therefore, the fitting ring **168** allows the plunger **165** and the shaft **164** to reciprocate and is rotated integrally with the plunger **165** and the shaft **164**.

As shown in FIG. **9**, the main elastic component **163** is a metal coil spring, and is accommodated in the vane **141**. The main elastic component **163** is interposed between the cylindrical slide part **166** and the inner flange part **144***a* in the axial direction. The main elastic component **163** generates restoring force biasing the main lock component **160** toward the rear plate **13** at a rotation position in the circumferential direction. Therefore, in the rotation phase from the main lock phase Pm to the secondary lock phase Ps, as shown in FIGS. **5-8**, the main lock component **160** receives the restoring force of the main elastic component **163** in an entering direction Im toward the main lock hole **162** or the guide slot **180**, thus, the main lock component **160** is biased in the entering direction Im. Moreover, due to the pressure from the main unlock chamber **161** to the cylindrical slide part **166**, the main lock component **160** receives the driving force in an escaping direction Em opposite from the entering direction Im against the restoring force of the main elastic component **163**, thus, the main lock component **160** is driven in the escaping direction Em, as shown in FIG. **8**.

Under this situation, the main lock phase Pm which is realized by the main lock component **160** entering the main lock hole **162** is set in advance at a most retard phase shown in FIGS. **2** and **14**. In this embodiment, the main lock phase Pm is set in advance, as shown in FIG. **15**, at a rotation phase for closing the intake valve **9** later than a timing at which the piston **8** in the cylinder **7** of the engine reaches the bottom dead center BDC.

A secondary lock mechanism **17** corresponding to a secondary lock member is described. As shown in FIGS. **3** and **4**, the secondary lock mechanism **17** is defined by combining a secondary elastic component **173** and a restriction slot **174** with the group of the secondary lock elements **170**, **171**, **172**.

The secondary elastic component **173** is a metal coil spring, and is accommodated in the vane **142**. As shown in FIG. **6**, the secondary elastic component **173** is interposed between spring receivers **142***a*, **170***a*, respectively provided to the vane **142** and the secondary lock component **170**, in the axial direction. The secondary elastic component **173** produces a restoring force to bias the secondary lock component **170** toward the rear plate **13**. Therefore, at the secondary lock phase Ps shown in FIGS. **7** and **8**, the secondary lock component **170** receives the restoring force of the secondary elastic component **173** in an entering direction Is, thus, the secondary lock component **170** is biased toward the secondary lock hole **172** in the entering direction Is. Moreover, due to the pressure from the secondary unlock chamber **171**, the secondary lock component **170** receives the driving force in an escaping direction Es opposite from the entering direction Is, and is driven in the escaping direction Es against the restoring force of the secondary elastic component **173**, as shown in FIG. **8**.

As shown in FIGS. **2**, **3**, and **6**, the restriction slot **174** is defined in the rear plate **13** with the based groove shape circularly extended along the rotational direction of the rotor **11**, **14**. The secondary lock hole **172** is further defined from the bottom of the restriction slot **174** with the based cylindrical shape at a halfway position of the restriction slot **174**.

When the secondary lock component **170** having the cylindrical shape enters the restriction slot **174** not overlapping with the secondary lock hole **172**, the rotation phase is restricted to a predetermined domain which includes the secondary lock phase Ps. Moreover, when the secondary lock component **170** enters the secondary lock hole **172** from the restriction slot **174**, the rotation phase is locked at the secondary lock phase Ps of FIG. **7**, because the rotation phase reaches the secondary lock phase Ps.

Under this situation, the secondary lock phase Ps realized by the secondary lock component **170** entering the secondary lock hole **172** is set in advance at the middle phase which is se on the advance side from the main lock phase Pm, as shown in FIGS. **3** and **14**. In this embodiment, the secondary lock phase Ps is set in advance, as shown in FIG. **15**, at a rotation phase for closing the intake valve **9** at just or adjacent timing at which the piston **8** in the cylinder **7** of the engine reaches the bottom dead center BDC.

A lock control mechanism **18** corresponding to a lock control member is described with reference to FIGS. **1**, **9**, and **10**. The lock control mechanism **18** is defined by combining the guide slot **180** and the temperature sensing member **182**, and controls the lock and unlock of the rotation phase by the main lock mechanism **16** and the secondary lock mechanism **17**.

As shown in FIGS. **2**, **3**, **9**, and **12**, the guide slot **180** is defined in the rear plate **13** with the based groove shape extended toward a predetermined permission point **183** from the main lock hole **162**. As shown in FIGS. **7** and **13**, the permission point **183** is a point corresponding to the secondary lock phase Ps at which the secondary lock component **170** is able to enter the secondary lock hole **172**.

At the secondary lock phase Ps, as shown in FIG. **7**, the secondary lock component **170** is at a point just corresponding to the main lock component **160** in the axial direction. As shown in FIG. **9**, the base of the guide slot **180** defines a sloped surface **180***a* which is a plane extending in the escaping direction Em as extending from the main lock hole **162** to the permission point **183**. Therefore, the depth of the guide slot **180** is set to gradually become shallow as going to the permission point **183** from the main lock hole **162**.

As shown in FIG. **13**, the guide slot **180** has a width which is larger than the width of the slide part **167** entering through the opening **162***c*, and extends with the linear (straight) shape. Therefore, the slide part **167** is able to slide in the guide slot **180** at the rotation phase from the main lock phase Pm shown in FIGS. **6**, **9**, and **12** to the secondary lock phase Ps shown in FIGS. **7** and **13**, and is guided to the permission point **183** from the main lock hole **162**.

Moreover, at this time, since the slide part **167** is biased by the main elastic component **163** in the entering direction Im, as shown in the double chain line of FIG. **9**, the slide part **167** is pressed to the sloped surface **180***a* and receives a drag. Due to the drag, as the slide part **167** goes along the sloped surface **180***a* toward the permission point **183**, the slide part **167** is pushed out in the escaping direction Em. As the result, in this embodiment, as shown in FIG. **7**, when the slide part **167** reaches the permission point **183**, the slide part **167** is completely outside the guide slot **180**.

A sloped angle of the sloped surface **180***a* is set in advance in consideration of the coefficient of friction of the slide part **167** against the sloped surface **180***a*, the magnitude of the restoring force of the main elastic component **163**, the magnitude of a negative torque at the time of starting, to be described later, when the temperature of the engine in the stopped state is low, and the seal length between the rotors **11** and **14** (that corresponds to the length S between the permission point **183** and the retard chamber **26** shown in FIGS. **5** and **6**).

As shown in FIG. **9**, the temperature sensing member **182** is located between the inner flange part **144***a* and the front plate **15**, in the support bush **144**. As shown in FIGS. **9**, **10**, and **16**, the temperature sensing member **182** is made of bimetal having a spiral shape in the same plane, and the center of the spiral shape is in agreement with the rotation center of the main lock component **160**.

The maximum inner circumference part **182***a* of the temperature sensing member **182** is engaged with the main lock component **160** by being wound around the outer circumference part of the fitting ring **168**. The maximum outer circumference part **182***b* of the temperature sensing member **182** is fixed and engaged with a projection part (not shown) of the inner circumference part of the support bush **144**. The temperature sensing member **182** is able to drive the main lock component **160** to rotate by the displacement of the maximum inner circumference part **182***a*.

As shown in FIG. **16**, the temperature sensing member **182** expands or shrinks based on the ambient temperature, and has a high expansion layer **184** and a low expansion layer **185**. The coefficient of thermal expansion is different between the high expansion layer **184** and the low expansion layer **185**. The high expansion layer **184** has a coefficient of linear expansion higher than that of the low expansion layer **185**, and is laminated on the outer circumference side of the low expansion layer **185**. The high expansion layer **184** may be made of nickel-chromium-iron (Ni—Cr—Fe) base alloy material, for example, and the low expansion layer **185** may be made of nickel-iron (Ni—Fe) base alloy material.

The temperature sensing member **182** expands or shrinks according to the engine temperature (ambient temperature), and the main lock component **160** is rotated by the maximum inner circumference part **182***a*. Specifically, when the engine temperature is higher than or equal to a preset temperature Ts (see FIGS. **18** and **19**), the temperature sensing member **182** is changed to an expanding state Se as shown in the double chain line of FIG. **16**.

At the main lock phase Pm of FIG. **5** where the main lock component **160** is located in the main lock hole **162**, the temperature sensing member **182** in the expanding state Se displaces the maximum inner circumference part **182***a* on a first side in the circumferential direction of the main lock hole **162**. Thereby, the slide part **167** is driven to rotate to the prohibition position Lp of FIG. **11**. Therefore, at this time, the main lock component **160** is prohibited from moving out of the main lock hole **162** toward the guide slot **180**.

The temperature sensing member **182** is changed to the shrinking state Sc shown in a solid line of FIG. **16**, when the engine temperature is lower than the preset temperature Ts. At the main lock phase Pm of FIG. **6** where the main lock component **160** is located in the main lock hole **162**, the temperature sensing member **182** displaces the maximum inner circumference part **182***a* on a second side which is opposite from the first side in the circumferential direction of the main lock hole **162**. Thereby, the slide part **167** is rotated to the allowance position Lc of FIG. **12**. Therefore, the main lock component **160** is allowed to escape from the main lock hole **162** toward the guide slot **180**.

In this embodiment, the preset temperature Ts set for the temperature sensing member **182** is defined to a temperature at which the slide part **167** is moved to the allowance position Lc from the prohibition position Lp. The preset temperature Ts is adjusted, for example, within a range of 40-60° C. by selecting the material for the layers **184**, **185**.

The variation torque applied from the camshaft **2** to the vane rotor **14** will be described.

While the engine is rotated, the variation torque is applied to the vane rotor **14** by the spring reaction force from the intake valve **9** which is opened and closed by the camshaft **2**. As shown in FIG. **17**, the variation torque fluctuates between the negative torque applied on the advance side to the housing rotor **11** and the positive torque applied on the retard side to the housing rotor **11**. The peak torque of the positive torque is larger than the peak torque of the negative torque, due to the friction between the camshaft **2** and the bearing, so the average torque is deviated on the positive torque (on the retard side).

A structure biasing the vane rotor **14** toward the secondary lock phase Ps is explained.

In the drive part **10** shown in FIG. **1**, a first stopper pin **110** and a second stopper pin **146** are respectively provided to the rotors **11** and **14**. The first stopper pin **110** has a pillar shape projected away from the shoe ring **12** in the axial direction from the front plate **15**. The second stopper pin **146** has a pillar shape projected in the axial direction toward the front plate **15** from an arm plate **147** of the rotation shaft **140** approximately parallel to the front plate **15**. The stopper pins

110, 146 are located at positions eccentric relative to the rotation central of the rotors 11, 14 by a substantially same distance, and are not overlap with each other in the axial direction.

The advance elastic component 19 is arranged between the front plate 15 and the arm plate 147. The advance elastic component 19 is made of metal plate material having a spiral shape in the same plane, and the center of the spiral shape is in agreement with the rotation center of the rotor 11, 14. The maximum inner circumference part of the advance elastic component 19 is wound around the outer circumference part of the rotation shaft 140. The maximum outer circumference part of the advance elastic component 19 is bent to have U-shape, and defines a locking part 190. The locking part 190 is able to be engaged with the corresponding pin 110, 146 corresponding to the rotation phase.

When the rotation phase is located between the lock phases Ps and Pm, that is on the retard side from the secondary lock phase Ps, the locking part 190 is engaged with the first stopper pin 110. At this time, since the second stopper pin 146 is separated from the locking part 190, the restoring force generated by the torsional elastic deformation of the advance elastic component 19 acts on the vane rotor 14 as an advance-side rotation torque relative to the housing rotor 11. That is, the vane rotor 14 is biased toward the secondary lock phase Ps on the advance side. The restoring force of the advance elastic component 19 between the lock phases Ps and Pm is set in advance so as to be larger than the average value of the variation torque (refer to FIG. 17) which is deviated on the retard side. On the other hand, when the rotation phase is changed to the advance side than the secondary lock phase Ps, the locking part 190 is engaged with the second stopper pin 146. At this time, since the first stopper pin 110 is separated from the locking part 190, the biasing action of the advance elastic component 19 to the vane rotor 14 is restricted.

Operations of the apparatus 1 are described.

Normal operation is described. While the engine has normal operation after starting and perfecting ignition, the spool 68 is moved to either of the domains Rr, Ra, Rh. At this time, as shown in FIGS. 18 and 19, the supply of operation oil from the pump 4 is continued at the high pressure according to the revolving speed of the engine. As a result, the main lock component 160 moves out of the main lock hole 162 and the guide slot 180, due to the pressure of operation oil introduced into the main unlock chamber 161 against the restoring force of the main elastic component 163 (FIG. 8). Further, the secondary lock component 170 moves out of the secondary lock hole 172 and the restriction slot 174 due to the pressure of operation oil introduced into the secondary unlock chamber 171 against the restoring force of the secondary elastic component 173 (FIG. 8). Thus, while the rotation phase is maintained to be unlocked relative to the lock phase Pm, Ps, the valve timing is adjusted suitably by the movement of the spool 68 which is changed into either of the domains Rr, Ra, Rh.

Stop operation and start operation are described. As shown in FIGS. 18 and 19, the engine is switched from the normal operation to a stop operation according to a stop directive such as off-instruction from the engine switch SW or idling stop instruction from the idling stop system ISS. First, in this embodiment, the spool 68 is moved to the lock domain RI before the engine is changed into an inertia rotation state by fuel cut. At this time, the supply of operation oil from the pump 4 is continued at the high pressure according to the revolving speed of the engine. Therefore, the rotation phase is changed by the operation oil pressure in the retard chambers 26, 27, 28 to the main lock phase Pm which is the most (maximum) retard phase.

After the change to the main lock phase Pm, the engine is changed into an inertia rotation state, then, as shown in FIGS. 18 and 19, the supply pressure of the operation oil from the pump 4 will decrease gradually according to the speed of the inertia rotation. At this time, since the pressure in the main unlock chamber 161 is lowered, the main lock component 160 which receives the restoring force of the main elastic component 163 enters the main lock hole 162 at a rotation position in the circumferential direction (FIG. 5). Since the pressure of the secondary unlock chamber 171 is lowered, the secondary lock component 170 which receives the restoring force of the secondary elastic component 173 contacts the rear plate 13 outside of the secondary lock hole 172 and the restriction slot 174 (FIG. 5). As a result, the engine stops completely in the state where the rotation phase is locked at the main lock phase Pm.

While the engine is stopped, when the temperature of engine is higher than or equal to the preset temperature Ts, as shown in FIG. 18, the slide part 167 in the main lock hole 162 is driven to rotate to the prohibition position Lp by the temperature sensing member 182 in the expanding state Se (FIG. 11). As a result, the main lock component 160 receives the restoring force of the main elastic component 163 in the state where the pressure in the main unlock chamber 161 is lowered, and the slide part 167 is fitted to the main lock hole 162, such that the slide part 167 is prohibited from moving out of the guide slot 180 (FIGS. 5 and 11). The secondary lock component 170 which receives the restoring force of the secondary elastic component 173 in the state where the pressure in the secondary unlock chamber 171 is lowered contacts the rear plate 13 outside of the secondary lock hole 172 and the restriction slot 174 (FIG. 5). As a result, the rotation phase is maintained to be locked at the main lock phase Pm.

Thereafter, in response to a start directive such as on-instruction from the engine switch SW or re-starting instruction from the idling stop system ISS, the cranking of the engine is started when the temperature of the engine is higher than or equal to the preset temperature Ts, as shown in FIG. 18, and the temperature sensing member 182 continues in the expanding state Se. At this time, the position of the spool 68 is held to the lock domain RI, and the supply of operation oil from the pump 4 is substantially stopped. Therefore, the main lock component 160 which receives the restoring force of the main elastic component 163 in the state where the pressure of the main unlock chamber 161 is lowered, and the slide part 167 at the prohibition position Lp in the main lock hole 162 is kept in the prohibited state prohibited from moving out of the guide slot 180 (FIG. 11). The secondary lock component 170 which receives the restoring force of the secondary elastic component 173 in the state where the pressure in the secondary unlock chamber 171 is lowered contacts the rear plate 13 outside of the secondary lock hole 172 and the restriction slot 174 (FIG. 5). As a result, as shown in FIG. 18, the engine perfects the ignition in the state where the rotation phase is locked at the main lock phase Pm.

While the engine is stopped, when the temperature of the engine is lower than the preset temperature Ts, as shown in FIG. 19, the slide part 167 in the main lock hole 162 is driven to rotate to the allowance position Lc by the temperature sensing member 182 which is changed to the shrinking state Sc (FIG. 12). As a result, the main lock component 160 which receives the restoring force of the main elastic component 163 in the state where the pressure in the unlock chamber 161 is lowered, the slide part 167 in the main lock hole 162 is changed from the prohibition state to the allowance state relative to the guide slot **180** (FIGS. **6** and **12**). The secondary lock component **170** which receives the restoring force of the secondary elastic component **173** in the state where the pressure in the secondary unlock chamber **171** lowered contacts the rear plate **13** outside of the secondary lock hole **172** and the restriction slot **174** (FIG. **6**). As a result, the rotation phase is unlocked from the lock phase Pm, Ps.

Thereafter, in response to a start directive such as on-instruction from the engine switch SW or re-starting instruction from the idling stop system ISS, when the cranking of the engine is started while the temperature of the engine is lower than the preset temperature Ts, as shown in FIG. **19**, the temperature sensing member **182** continues in the shrinking state Sc. At this time, the position of the spool **68** is held to the lock domain RI, and the supply of operation oil from the pump **4** is substantially stopped. Therefore, the main lock component **160** which receives the restoring force of the main elastic component **163** in the state where the pressure in the main unlock chamber **161** is lowered, the slide part **167** at the allowance position Lc in the main lock hole **162** is maintained to be allowed to move out of the guide slot **180** (FIGS. **6** and **12**). The secondary lock component **170** which receives the restoring force of the secondary elastic component **173** in the state where the pressure in the secondary unlock chamber **171** is lowered contacts the rear plate **13** outside of the secondary lock hole **172** and the restriction slot **174** (FIG. **6**).

Thus, when the engine is started under the situation where the temperature of the engine is low and the rotation phase is unlocked from the lock phase Pm, Ps, the vane rotor **14** is rotated on the advance side relative to the housing rotor **11** by the action of negative torque. At this time, the main lock component **160** supported by the vane rotor **14**, the slide part **167** is moved from the allowance position Lc into the guide slot **180** through the opening **162***c* by the action of negative torque, and is further guided toward the permission point **183** inside the slot **180** (double chain line of FIG. **9**). As a result, when the rotation phase is advanced from the main lock phase Pm, the secondary lock component **170** which receives the restoring force of the secondary elastic component **173** in the state where the pressure in the secondary unlock chamber **171** is lowered is allowed to enter the restriction slot **174**. Therefore, when the vane rotor **14** to which the positive torque is applied is rotated on the retard side relative to the housing rotor **11**, the rotation phase is restricted from returning to the main lock phase Pm, as shown in FIG. **19**.

Then, when the rotation phase is further advanced by the action of negative torque to the secondary lock phase Ps, the secondary lock component **170** which receives the restoring force of the secondary elastic component **173** in the state where the pressure in the secondary unlock chamber **171** is reduced is allowed to enter the secondary lock hole **172** (FIG. **7**). At this time, the slide part **167** is pushed out in the escaping direction Em by the drag action from the sloped surface **180***a*, in the main lock component **160** which receives the restoring force of the main elastic component **163** in the state where the pressure in the main unlock chamber **161** is lowered (FIGS. **7** and **13**). As a result, the secondary lock component **170** is fitted to the secondary lock hole **172**, and the slide part **167** contacts the rear plate **13** outside of the main lock hole **162** and the guide slot **180**. Therefore, as shown in FIG. **19**, the engine perfects the ignition in the state where the rotation phase is changed to be locked at the secondary lock phase Ps.

Advantage of the embodiment is explained below.

At the main lock phase Pm, while the engine is stopped with temperature higher than or equal to the preset temperature Ts, the main lock component **160** is prohibited from moving out of the main lock hole **162** to the guide slot **180** by expansion of the temperature sensing member **182**. As a result, the rotation phase is locked at the main lock phase Pm, while the main lock component **160** maintains to stay in the main lock hole **162**. At the main lock phase Pm, the intake valve **9** is closed late timing later than a timing at which the piston **8** in the cylinder **7** reaches the bottom dead center BDC.

At the next time starting the engine, the gas in the cylinder **7** is pushed out to the intake system according to the lift-up of the piston **8** after reaching the bottom dead center, and a real compression ratio is lowered as a decompression effect. Therefore, when the engine is frequently and repeatedly re-started by the idol stop system ISS, for example, under the temperature of the engine is high, the rotation phase maintains to be locked at the main lock phase Pm, and the starting fault can be controlled.

On the other hand, at the main lock phase Pm, while the engine is stopped with temperature lower than the preset temperature Ts, the rotation phase is unlocked by the shrinking of the temperature sensing member **182**, so the main lock component **160** is able to move out of the main lock hole **162**. Therefore, at the next time starting the engine, the main lock component **160** is allowed to move out of the main lock hole **162** into the guide slot **180**, due to the variation torque applied from the camshaft **2**, and is guided toward the permission point **183**, and the vane rotor **14** is relatively rotated to the advance side relative to the housing rotor **11**. As a result, when the rotation phase is changed to the secondary lock phase Ps that is located on the advance side than the main lock phase Pm, the secondary lock component **170** is allowed to enter the secondary lock hole **172**, and the rotation phase is locked at the secondary lock phase Ps. Thus, the timing closing the intake valve **9** becomes early as much as possible. Thereby, the push-out amount of the gas in the cylinder **7** decreases, and the temperature of the gas rises with the real compression ratio. Accordingly, when the engine is restarted in the situation where the temperature of the engine is low, for example, when the vehicle is started after long time while the vehicle is parked in the very low temperature environment, or when the engine is restarted after the vehicle is stopped by the idol stop system ISS as a temporary halt, the startability can be secured by raising the ignitionability.

Accordingly, it becomes possible to start the engine suitably for the temperature of the engine.

At the main lock phase Pm while the engine is stopped with the temperature higher than or equal to the preset temperature, the main lock component **160** is rotated to the prohibition position Lp in the circumferential direction of the main lock hole **162** by the temperature sensing member **182** in the expanding state Se, and is prohibited from moving out of the guide slot **180**. In this way, when the rotation phase is located at the main lock phase Pm while the engine is started with the temperature higher than or equal to the preset temperature, the rotation phase is maintained at the main lock phase Pm, and the starting fault may be controlled.

Moreover, at the main lock phase Pm while the engine is stopped with the temperature lower than the preset temperature, the main lock component **160** is rotated to the allowance position Lc in the circumferential direction of the main lock hole **162**, and is allowed to move out of the main lock phase Pm to the guide slot **180**, due to the temperature sensing member **182** in the shrinking state Sc. In this way, when the rotation phase is unlocked from the main lock phase Pm while the engine is started with the temperature lower than the preset temperature, the rotation phase is changed to the secondary lock phase Ps by the variation torque, and the startability may be secured.

Accordingly, the expanding or shrinking of the temperature sensing member **182** according to the engine temperature and the rotation of the main lock component **160** can accurately control the rotation phase suitably based on the engine temperature when the engine is started.

Moreover, the slide part **167** entering the main lock hole **162** at the main lock phase Pm while the engine is stopped with the temperature higher than or equal to the preset temperature is driven to rotate to the prohibition position Lp by the temperature sensing member **182** in the expanding state Se. Thereby, a gap is produced in the circumferential direction relative to the opening **162***c* of the guide slot **180** which is located at a specific part in the circumferential direction. According to this, the slide part **167** is certainly forbidden from escaping from the main lock hole **162** through the opening **162***c*, and the rotation phase maintains to be locked at the main lock phase Pm.

On the other hand, the slide part **167** entering the main lock hole **162** at the main lock phase Pm while the engine is stopped with the temperature lower than the preset temperature is rotated to the allowance position Lc by the temperature sensing member **182** in the shrinking state Sc, and becomes able to enter the opening **162***c* of the guide slot **180**. According to this, the slide part **167** is certainly allowed to enter the opening **162***c* from the main lock hole **162**, and the rotation phase is unlocked from the main lock phase Pm.

Further, when the rotation phase changes to the secondary lock phase Ps in the state where the engine is stopped with the temperature lower than the preset temperature, the slide part **167** slides in the guide slot **180**. Therefore, the main lock component **160** is surely guided to the permission point **183**, and the secondary lock component **170** can enter the secondary lock hole **172**. Accordingly, the rotation phase is locked or unlocked suitably based on the engine temperature, and it becomes possible to improve reliability about the change in the rotation phase suitably based on the engine temperature when the engine is started.

Furthermore, the temperature sensing member **182** having the spiral shape expands or shrinks at the main lock phase Pm, thereby displacing the maximum inner circumference part **182***a* in the circumferential direction of the main lock hole **162**. Thereby, the main lock component **160** engaged with the maximum inner circumference part **182***a* is surely rotated between the prohibition position Lp and the allowance position Lc. Because the main lock component **160** is rotated to lock or unlock the rotation phase according to the engine temperature, it becomes possible to improve reliability about the change in the rotation phase suitably based on the engine temperature when the engine is started.

Furthermore, while the engine is started with the low temperature, the main lock component **160** is guided by the guide slot **180** from the main lock hole **162** to the permission point **183** in response to the change in the rotation phase. At this time, the main lock component **160** receives the biasing force from the main elastic component **163** in the entering direction Im toward the main lock hole **162** or the guide slot **180**. Therefore, the main lock component **160** which receives the biasing force from the main elastic component **163** is pressed to the sloped surface **180***a* of the guide slot **180** which is inclined to the escaping direction Em opposite from the entering direction Im as extending from the main lock hole **162** to the permission point **183**. As a result, the main lock component **160** receives the drag from the sloped surface **180***a* while going to the permission point **183**, thereby being able to be pushed out from the guide slot **180** in the escaping direction Em opposite from the entering direction Im against the biasing force of the main elastic component **163**. According to this, the main lock component **160** is moved out of the guide slot **180**, and the flexible valve timing adjustment can be achieved by subsequent change in the rotation phase.

In addition, in the rotation phase between the main lock phase Pm and the secondary lock phase Ps, the vane rotor **14** is biased by the advance elastic component **19** to the advance side relative to the housing rotor **11**. Therefore, when the engine is started with low temperature, the rotation phase of the vane rotor **14** relative to the housing rotor **11** can be quickly changed to the secondary lock phase Ps, due to the advance elastic component **19** and the variation torque. Thus, the time period taken to lock the rotation phase at the secondary lock phase Ps from the start of cranking which generates the variation torque in the engine at the time of starting the engine with low temperature can be shortened. It becomes possible to improve reliability of the startability especially when the engine is started with the low temperature.

MODIFICATIONS

The present disclosure is not limited to the above embodiment.

As a first modification, as shown in FIG. **20**, the guide slot **180** may be extended with the curved shape along the rotational direction of the rotors **11** and **14**, and the long surface **167***a*, **167***b* of the slide part **167** may have the curved shape corresponding to the curved shape of the guide slot **180**.

As a second modification, as shown in FIG. **21**, the guide slot **180** may not have the sloped surface **180***a*. The main lock component **160** may leave the slot **180** only according to the operation oil pressure in the main unlock chamber **161**.

As a third modification, as shown in FIG. **22**, the main lock component **160** may leave the guide slot **180** only by the drag from the sloped surface **180***a* without forming the main unlock chamber **161**.

As a fourth modification, the both ends of the temperature sensing member **182** having the spiral shape may be fitted to the main lock component **160** (fitting ring **168**) and the vane rotor **14** (support bush **144**), respectively.

As a fifth modification, the temperature sensing member **182** and the lock component **160**, **170** may be supported by the housing rotor **11** support, and the slot **180**, **174** and the lock hole **162**, **172** may be defined in the vane rotor **14**.

As a sixth modification, the elastic component **163**, **173** may be made of metal spring other than the coil spring or rubber.

As a seventh modification, the pump **4** may be electric pump which can start supplying operation oil in connection with the complete ignition in the engine or arbitrary timing.

As an eighth modification, the main lock phase Pm may be set on the advance side than the maximum retard phase, if the intake valve **9** is closed later timing later than the timing at which the piston **8** in the cylinder **7** reaches the bottom dead center BDC.

As a ninth modification, the secondary lock phase Ps may be set at a rotation phase where the intake valve **9** is closed at early timing as much as possible than the timing at which the piston **8** in the cylinder **7** reaches the bottom dead center BDC.

As a tenth modification, it may not be necessary to form the advance elastic component **19**. In this case, the movement of the spool **68** to the lock domain RI and the inertia rotation of the engine are performed in opposite order.

As an eleventh modification, when the engine stops according to off instruction from the switch SW, the rotation phase may be locked at the secondary lock phase Ps. Thereafter, when the engine starts according to on instruction from the switch SW, the lock at the phase Ps may be realized as it is.

As a twelfth modification, when the engine stops according to idol stop instruction from the system ISS, the rotation phase may be locked at the secondary lock phase Ps. Thereafter, when the engine starts according to re-starting instruction from the system ISS, the lock at the phase Ps may be realized as it is.

Such changes and modifications are to be understood as being within the scope of the present disclosure as defined by the appended claims.

What is claimed is:

1. A valve timing control apparatus which controls a valve timing of an intake valve opening and closing a cylinder of an internal combustion engine by a pressure of hydraulic fluid, the valve timing control apparatus comprising:

a housing rotor which is rotated with a crankshaft of the internal combustion engine;

a vane rotor which is rotated with a camshaft of the internal combustion engine, the vane rotor receiving the pressure of hydraulic fluid in the housing rotor such that a rotation phase of the vane rotor relative to the housing rotor is changed;

a main lock member having a main lock component and a main lock hole which are engaged with each other to lock the rotation phase at a main lock phase for closing the intake valve later than a timing at which a piston in the cylinder reaches a bottom dead center;

a secondary lock member having a secondary lock component and a secondary lock hole which are engaged with each other to lock the rotation phase at a secondary lock phase which is set on an advance side than the main lock phase; and

a lock controller which controls lock and unlock of the rotation phase by controlling the main lock member and the secondary lock member, wherein the lock controller has

a guide slot which guides the main lock component from the main lock hole toward a permission point at which the secondary lock component is allowed to enter the secondary lock hole at the secondary lock phase, and

a temperature sensing member which expands at the main lock phase when a temperature of the engine is higher than or equal to a predetermined temperature so as to prohibit the main lock component from moving out of the main lock hole toward the guide slot, wherein

the temperature sensing member shrinks at the main lock phase when the temperature of the engine is lower than the predetermined temperature so as to allow the main lock component to move out of the main lock hole toward the guide slot.

2. The valve timing control apparatus according to claim **1**, wherein

the main lock component is able to rotate in a circumferential direction of the main lock hole between a prohibition position where the main lock component is prohibited from moving out at the main lock phase and an allowance position where the main lock component is allowed to move out at the main lock phase, and

the temperature sensing member is changed based on the temperature of the engine between an expanding state in which the main lock component is driven to rotate to the prohibition position and a shrinking state in which the main lock component is driven to rotate to the allowance position.

3. The valve timing control apparatus according to claim **2**, wherein

the guide slot is defined at a predetermined position of the main lock hole in the circumferential direction,

the main lock component has a slide part which rotatably enters the main lock hole at the main lock phase and which slides into the guide slot at the rotation phase from the main lock phase to the secondary lock phase,

the prohibition position is a rotation position where the slide part is deviated from an opening of the main lock hole corresponding to the guide slot in the circumferential direction of the main lock hole, and

the allowance position is a rotation position where the slide part is able to enter the opening of the main lock hole corresponding to the guide slot.

4. The valve timing control apparatus according to claim **2**, wherein

the temperature sensing member has a spiral shape, and a maximum inner circumference part of the spiral shape is engaged with the main lock component, and

the maximum inner circumference part is displaced in the circumferential direction of the main lock hole by the expanding and the shrinking at the main lock phase.

5. The valve timing control apparatus according to claim **1**, wherein

the main lock member has a main elastic component which biases the main lock component toward the main lock hole or the guide slot in an entering direction at the rotation phase from the main lock phase to the secondary lock phase, and

the guide slot defines a sloped surface which is inclined in an opposite direction opposite from the entering direction as going toward the permission point from the main lock hole.

6. The valve timing control apparatus according to claim **1**, further comprising:

an advance elastic component which biases the vane rotor on the advance side relative to the housing rotor at the rotation phase between the main lock phase and the secondary lock phase.

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